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PRELIMINARY
FOCUSED RISK ASSESSMENT
FOR WEST CHICAGO
VICINITY PROPERTIES

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

REPLY TO THE ATTENTION OF:

NOTE TO READERS

In September 1991, U.S. EPA initiated a focused risk assessment of several contaminated properties in West Chicago. The focused risk assessment was conducted in order to compare the risks to human health from contaminated soils in yards to the risks that might result from placing the contaminated soils in a temporary storage location.

On February 19, 1993, U.S. EPA met with State regulatory agencies, the City, and other governmental representatives to review the status of the overall cleanup process for contaminated residential areas, and to discuss the focused risk assessment. There were several concerns raised about the amount of data used in the risk assessment and some of the assumptions that formed the basis for the work. U.S. EPA intended the focused risk assessment to be an estimate of the risk range at locations in the community. Nevertheless, because of the concerns raised, including comments from the Illinois Department of Nuclear Safety (IDNS), U.S. EPA agrees that the risk assessment and summary of findings should be considered "PRELIMINARY" at this time, and that further data collection and discussion of assumptions are appropriate.

U.S. EPA, in conjunction with IDNS, will collect additional data from contaminated properties to more thoroughly characterize the risk range. Based on the results of this additional work, U.S. EPA may find it necessary to revise the preliminary focused risk assessment. Once any revisions are made, U.S. EPA will issue a "final" focused risk assessment and summary of findings.

United States Environmental Protection Agency
Region 5
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Chicago, Illinois 60604
Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin

EPA

Summary of Findings
West Chicago-Area Preliminary Risk Study

U.S. EPA initiated a focused risk assessment of the residential areas in September 1991. Its purpose was to compare the risk from the contamination in yards and other properties with the risk from placing contaminated soils in a temporary storage location. For purposes of the risk assessment work, U.S. EPA assumed that contaminated soils would be stored temporarily at the Kerr-McGee factory site. (For more information regarding temporary storage options see page 5-6.)

U.S. EPA's study is called a focused risk assessment. The risk assessment is "focused" because it is not intended to be a complete assessment of all possible risks associated with all the contaminated properties included in the residential areas under investigation by U.S. EPA. Rather, U.S. EPA's intent is to calculate the potential range of current and future cancer risks at selected contaminated properties, and the impact on human health risks if soils from contaminated properties are placed on the Kerr-McGee factory site (or other locations) for temporary storage, in order to provide a basis for decision-making with citizens and community officials. This focused risk assessment is based upon limited data and a conservative assumption that persons were exposed to the highest radioactive levels found. Risks could be lower than those presented here for the properties that were studied.

The focused risk assessment study examined seven properties (four residences and three schools) contaminated with radioactive thorium mill tailings, and evaluated the general range of cancer risks associated with the contamination at those properties. Although the number of properties and the data used in the study were very limited, U.S. EPA believes that the results of the study provide an indication of the general risk range that possibly may be present at these and other contaminated properties. However, U.S. EPA has agreed to call the study a PRELIMINARY focused risk assessment, to collect additional data, and to revise the preliminary study if the data shows it to be necessary.

The results of the preliminary study indicate that health risks at the contaminated residential properties that were studied are of greatest potential concern for both current and future land use, with cancer risks generally above what U.S. EPA considers as acceptable. The school properties show considerably lesser risk, especially for current land use, but may be of more concern in the future if land use changes and homes are built on top of the contamination. In addition, the study indicates that the option of temporarily storing wastes on the Kerr-McGee factory site (or other similar locations) would result in a small incremental increase in risk to residents living adjacent to the factory site.

Why was this preliminary risk assessment conducted?

U.S. EPA is concerned about the possible cancer risks associated with contaminated soils at residential properties, and recognizes the concerns of members of the community regarding the option of temporarily storing wastes at the Kerr-McGee factory site. U.S. EPA has attempted, with limited data, to assess the risks for both situations so that meaningful discussions with citizens and public officials about possible solutions can take place.

When U.S. EPA finds potentially unacceptable health risks to the public from a Superfund site, U.S. EPA's objective is to reduce the risk as quickly as possible to protect human health and the environment. In the case of the Residential Areas site, U.S. EPA plans to remove contaminated soil from properties as quickly as possible to prevent residents from continuing to be exposed to potentially harmful levels of radiation.

Typically, a full risk assessment, known as a "baseline risk assessment," is not conducted for sites where removal actions are planned, because an extensive amount of data and time are needed to complete such a study. A baseline risk assessment involves studying all cancer and non-cancer health risks caused by all contamination associated with a Superfund site to determine if there is sufficient risk to take action. Conducting a baseline risk assessment is not necessary at the Residential Areas site because it is already well known that risks from radiation exposure exist.

Although U.S. EPA judged that conducting a baseline risk assessment was inappropriate for this site, the Agency believed that a limited, focused assessment of the risks associated with residential contamination and with a possible removal option would be useful for decision-making purposes. The Illinois Department of Nuclear Safety (IDNS) already had collected some data as part of its ongoing surveillance activities, so U.S. EPA decided to use some of the available data to conduct a limited risk assessment of seven properties to establish the general levels of risk. U.S. EPA will work with IDNS to gather additional data to refine the preliminary risk analysis if needed.

U.S. EPA recognizes that there may be differing concerns within the West Chicago community. Some members of the community may be concerned most about the risks caused by contaminated residential properties, and others may be more concerned about any increased risk from temporarily storing contaminated soils at various sites. U.S. EPA hopes that the information in this focused risk assessment will help members of the community and public officials understand the levels of potential risk associated with these properties and the decisions facing U.S. EPA regarding temporary storage of contaminated soils.

How was the focused risk assessment conducted?

There were several steps involved in conducting this risk assessment. First, U.S. EPA looked at what kind of contamination is present, its concentration, and in what media (e.g., soil, water) it is present; secondly, it studied the characteristics of the population and the properties involved. From these first two steps, U.S. EPA identified pathways by which people may be exposed to the contamination, such as spending time in their yards where gamma radiation may be given off by contaminated soil. After these steps were completed, mathematical formulas were used to calculate an estimate of the amount of radiation that the population is receiving from each pathway of exposure, and whether undesirable health effects, such as cancer, might result from this exposure.

For the residential and school property risk assessment, U.S. EPA focused on radioactive contamination, because it is the primary source of risk to human health and the environment at this site. To characterize the population at the seven properties, U.S. EPA made assumptions about the number of hours people spent inside and outside of their homes and inside and outside of their schools. For schools, U.S. EPA made different assumptions about the schedules of teachers and students. For residences, U.S. EPA considered the different lifestyle patterns of children, teenagers, and adults. In addition, U.S. EPA assumed that residents had vegetable gardens and fruit trees planted in their yards as sources of food. These assumptions were based on standard U.S. EPA risk assessment methods for estimating the maximum exposures that people might reasonably be expected to receive. **U.S. EPA's intent was not to evaluate the risk for an average exposure, but rather the risk that might reasonably be expected to occur for a maximally exposed individual.**

To identify the pathways that could expose residents to contamination, U.S. EPA examined its assumptions about the characteristics and lifestyle patterns of the population. U.S. EPA concluded that residents could be exposed to radioactive contamination by being outside in yards with contaminated soil; by eating vegetables and fruits grown in contaminated soils; by accidentally eating contaminated soil (both children and adults); by breathing in contaminated soil particles in the air; and by inhaling decay products from radioactive gas that might seep from soil into homes through the foundations. U.S. EPA also evaluated the risks in a worst-case future scenario in which properties are re-developed, and new homes are built directly in and over contaminated soil.

To assess the added risk of creating a new temporary storage pile at the factory or some other site, U.S. EPA only considered gamma radiation emitted from the storage pile. U.S. EPA focused on gamma radiation because it assumed the storage pile would be covered, and only gamma radiation would be able to penetrate through a cover. Exposure to gamma radiation was considered for individuals standing at the nearest fenceline to the proposed storage pile as well as for individuals living at the closest residence.

Airborne particles of contamination (dust or radon and thoron decay products) were not evaluated because maintenance of a cover would eliminate this possibility. Accidental puncture of the cover or exposure to trespassers on the factory site were not considered because U.S. EPA assumed that security around the factory site would remain in place to prevent trespassers from entering the site.

The evaluation of the temporary storage pile scenario in the focused risk assessment was limited because of the purpose of the study and the data available. The study evaluated only the additional risks due to a new storage pile, not the total risks due to existing tailings or other wastes already on the site. The study also was limited in that it considered temporary storage of soil only from the seven properties (schools and residences) that were included in the study, and not from any other properties that may require removal actions. However, the study estimated what the risks might be if five times more soil were included in the pile, to consider the impact on risk levels if soil from other properties was stored at the site.

What are EPA's conclusions about current health risks from these properties?

For the three schools included in the study (preschool, junior high, and high school), U.S. EPA calculated the maximum increased cancer risk for school children to be about 2 in 100,000. This means that if 100,000 students were exposed, at most two children could contract cancer as a result of exposure to the contamination. U.S. EPA based this calculation on the assumption that the children would attend a school for 2-4 years and contamination would not be removed sooner. For teachers, U.S. EPA calculated the increased cancer risk to be about 5 in 100,000. The increase for teachers compared to students is due to the assumption that teachers spend a longer period of time at the schools each day, and would teach at the same school for 25 years. Again, these assumptions are based on standard U.S. EPA risk assessment guidance documents and that contamination is not removed. U.S. EPA found that the risks at the school properties are primarily from exposure to gamma radiation while outside of the school buildings.

U.S. EPA evaluated four residences in this study. At one of the residences, U.S. EPA calculated the maximum increased cancer risk could be about 3 in 1,000. This means that if 1,000 residents were exposed for 30 years to the same level of contamination under the same conditions as in this study, three people could contract cancer from the radiation contamination. Risks were considerably lower at the other three residences (2 to 7 in 10,000). Again, this assumes that contamination is not removed. U.S. EPA based its calculations on the assumption that residents would occupy their homes for 30 years, U.S. EPA's standard estimate for the time period most people live in one home. U.S. EPA accounted for different exposure levels for residents working at home and spending more time on the property, and for residents who work a full-time job away from their home. In addition, U.S. EPA projected the maximum amount of time residents might reasonably be expected to spend indoors and outdoors, and assumed that the majority of fruits and vegetables in their diet were grown in contaminated soil on the property.

At one of the four residences, the risks are primarily from the exposure to gamma radiation while outside of the residence. Inhalation and ingestion are the major contributors to risk at the other three residences because asphalt and upper layers of soil are shielding people from gamma radiation exposure.

What are EPA's conclusions about health risks from these properties in the future?

To calculate potential future risks, U.S. EPA assumed a worst-case scenario in which none of the properties are cleaned up, and new homes are constructed in and over the highest level contaminated soils on each of the properties. This is a standard Superfund risk assessment approach. It was assumed that any asphalt or soil that would shield contamination where the new homes are built would be removed. U.S. EPA also assumed that each individual would live in the home 30 years, including 6 years as a child, and spend 75 percent of their time in the house.

U.S. EPA determined that the most significant source of risk in the future scenario would be gamma radiation from being outdoors on the properties, and the indoor exposure to decay products from radioactive gas seeping into the new homes through the foundation from contaminated soil. The expected increase in lifetime cancer risk varied at different residential properties, and ranged from 6 to 90 in 1,000. These figures mean that if 1,000 people were exposed to the property's varying levels of contamination, between 6-90 people could contract cancer due to the exposure. On the school properties, the increased cancer risk for a future residential scenario is about 7 in 1,000. Again, because risks are based upon limited data and the assumption that people would be exposed to the highest radiation levels found, **future risks could be lower.**

U.S. EPA did not calculate the maximum risks possible for exposure to gamma radiation outside the newly constructed homes, because it was assumed that asphalt and upper layers of soil elsewhere on the properties would stay in place, shielding residents from gamma radiation. However, if this asphalt and soil were removed, allowing more exposure to gamma radiation, U.S. EPA estimates that the additional gamma radiation received by people outside their homes would not significantly increase the total risks for the future scenario.

Comparing Risks. U.S. EPA's Superfund program generally considers site-related cancer risks greater than 1 in 10,000 as unacceptable, and will seek to reduce these risks. To help people understand the cancer risks discussed here, and to compare them with cancer risks from other environmental sources not related to the Superfund site, some lifetime cancer risks are shown in the box at right.

Cancer-Causing Sources or Situations	Approximate Lifetime Risk of Cancer
Cigarette smoking (a pack or more a day)	8 in 100
Natural radon in indoor air at home (U.S. average)	1 in 100
Outside radiation (natural radon and cosmic rays)	1 in 1,000
Outdoor air in industrialized areas	1 in 10,000

What are EPA's conclusions about increased health risks from using the factory site for temporary storage?

Because a long-term, permanent disposal facility is not available yet for any of the contaminated soils that need to be removed, a temporary storage location will be necessary if risks are to be reduced through removal actions at the contaminated properties. Since removals cannot be conducted until there is a place to take the materials, U.S. EPA evaluated the option of temporarily storing the soil at the Kerr-McGee factory site until a permanent disposal facility is available. Therefore, the focused risk assessment examined how the risk to nearby residents might change if the factory site were used as a temporary storage facility. **U.S. EPA also is evaluating other options for temporary storage of soils, but those options were not sufficiently developed to include in this preliminary risk assessment.**

The results of U.S. EPA's calculations are summarized below. To better understand the results, however, a short description is necessary. U.S. EPA assumed the pile on the factory site would be positioned so that its edge would be approximately 50 feet from the west property fence line which borders the Elgin, Joliet, and Eastern Railroad tracks. U.S. EPA calculated the additional gamma exposure rate for a person standing at the fenceline closest to the storage pile, and the additional exposure rate and health risks to residents living at the closest residence. As explained earlier, U.S. EPA only considered risks from gamma radiation due to the new storage pile at the factory site (see p. 3 on how the risk assessment was conducted).

Increases in Exposure to Radiation at the Fenceline. Current levels of radiation at the factory site near the proposed location of the storage pile are greater than natural background due to the existing contaminated waste piles left over from past manufacturing activities and past residential cleanups. Data from the Illinois Department of Nuclear Safety shows that actual current radiation levels at the closest fenceline west of the proposed location of the storage pile range from 39 to 110 microroentgens/hour. U.S. EPA calculated that for a person standing at the closest fenceline west of the proposed location of the storage pile (50-100 feet away), the proposed storage pile would increase that person's level of radiation exposure by 1 to 4 microroentgens/hour, an increase of 5-10 percent from current levels.

Risks to Residents Nearest the Factory Site. The distance from the edge of the proposed storage pile to the nearest residence is approximately 400 feet. At that distance, the increase in exposure rate caused by the pile would be approximately 0.1 microroentgen/ hour, which would be hard to distinguish from any existing levels. U.S. EPA estimated that for the nearest resident, a person's exposure to radiation and related health risks would increase by no more than 1 percent above existing levels if a new storage pile were created.

Based on an increase of 0.1 microroentgens/hour from the proposed storage pile, U.S. EPA considered the exposure level of an individual at home 75 percent of the day for 350 days each year. U.S. EPA calculated that the annual dose to the resident from the proposed storage pile could be as great as 0.53 millirems/year. The increased cancer risk resulting from an annual dose of 0.53 millirems, for 30 years of exposure, is 1 in 100,000. This means that if 100,000 people were exposed for 30 years to the same level of contamination from the proposed storage pile as at the nearest residence, one person could contract cancer in his/her lifetime from that exposure. (NOTE: U.S. EPA based its calculations on 30 years of exposure in order to be consistent with how risks were calculated for residents on Residential Area site properties. The Agency does not intend to imply that contaminated soils would be temporarily stored at the factory site for 30 years, but only wanted to be able to compare similar risks.)

Conclusion. Based on this focused risk assessment, the risks are much lower for temporary storage at the factory site and possibly other locations than if the contaminated soils are allowed to remain in place at residences.

Limitations of the Risk Assessment

As previously discussed, U.S. EPA recognizes that its focused risk assessment was limited in the amount of data, the number of properties, and the kind of assumptions and estimates that were made. U.S. EPA also recognizes that this may be a cause for public concern. Despite these limitations, U.S. EPA believes that the assumptions and projections in the study cover the range of contamination that is likely to be encountered at properties in and around West Chicago; additional data will be collected, however, and the preliminary risk assessment revised, if necessary. U.S. EPA has attempted to identify the highest reasonably expected risks from contamination at the properties. The limitations and related concerns are summarized below.

Limitations related to the current and future Residential Area site properties. Some people may believe that too few soil samples were included in the risk assessment, because in most cases a single soil sample from each property was used as the basis of U.S. EPA's calculations. For each of the seven properties, U.S. EPA chose the soil sample containing the highest level of contamination and assumed that this level of contamination exists throughout all the contaminated soil on the property. Some scientists may think that U.S. EPA's assumptions are far too cautious and conservative, and that the calculations made by U.S. EPA will over-estimate the risks and cause public alarm. U.S. EPA recognizes that its assumptions may have resulted in over-estimating the level of risk for some of the properties. However, U.S. EPA did not want limited soil samples to cause them to underestimate potential risks from undetected contamination on the properties. Where there were uncertainties in the focused risk assessment, U.S. EPA decided to err on the conservative side to ensure that human health and the environment are protected.

Only a limited number of properties could be included in the focused risk assessment because extensive data has not yet been collected at most of the contaminated properties. It is necessary to have both gamma radiation measurements and soil concentration data to accurately evaluate risk. Therefore, U.S. EPA evaluated only those properties with the most usable data. U.S. EPA and IDNS will gather additional samples from contaminated properties to determine if the preliminary risk assessment conclusions need refinement.

Some people may be concerned about the limited number of properties included in the assessment because some of the properties had small areas of contamination, and it is likely that residential properties not included in the assessment have much larger contaminated areas. Again, U.S. EPA compensated for this by assuming that all contaminated soil was contaminated at the level of the most highly contaminated soil sample found on each property. This helped U.S. EPA assess the level of risk that might exist at a property with a larger amount of contamination.

Some people may argue that U.S. EPA's assumptions about the pathways do not apply to the people living on or visiting the contaminated properties, and that some pathways weren't considered at all. Standard guidance and procedures were followed by U.S. EPA in this risk assessment, and U.S. EPA used conservative assumptions to make sure that if there was error, it was on the side of caution and protection of human health and the environment. The amount of fruits and vegetables estimated to be grown in contaminated soil and eaten by residents may be considerably higher than occurs in most families, and the assumed number of hours people spend indoors and outdoors may not be considered typical. However, U.S. EPA used standard risk assessment methods and assumptions to consider living patterns that would include the potential levels of radiation that people could reasonably be exposed to, and to make sure that the risks were not underestimated. Based on a general review of the assumptions and uncertainties that occurred in the focused risk assessment, U.S. EPA estimates that the risks could be overestimated by as much as 3 to 10 times the actual risks.

U.S. EPA did determine that some pathways were unlikely, and eliminated them from consideration. For example, dairy farming or beef production were not included as future possible activities on contaminated property, because dairy or beef production activities do not currently occur in the West Chicago area. No drinking water pathway for public exposure was included because current groundwater data shows no evidence of radioactive contamination connected with the site in municipal or private water supply wells, and the contaminants of concern are very insoluble in water.

Limitations related to the proposed temporary storage site. Some people may be concerned that U.S. EPA used too few soil samples from the properties to determine the risks of storing contaminated soil at the factory site. Based on the levels of contamination found in these samples, U.S. EPA projected the level of contamination in the soil that would be placed in temporary storage at the factory site. Although U.S. EPA was conservative and chose the samples with the highest contamination levels for its calculations, it is possible that soils with a higher concentration of radioactive contaminants exist, but were not found. This could have occurred if the contamination is buried below asphalt or so deeply that it does not show up in surveys.

Some people may be concerned that the risks were calculated using only the volume of soil to be removed from the seven properties. To address this concern, U.S. EPA estimated how much the risks would increase if the storage pile included five times the volume of soil removed from the seven properties. U.S. EPA determined that if the volume of the pile was increased five times, the exposure rate would increase three times. At large distances the exposure rate would not change greatly, but at the nearest residence, the exposure rate would increase from 0.1 microroentgens/hour to 0.31 microroentgens/hour. If the volume of soil were larger than five times the volume of soil removed from the seven properties, an additional increase in risk would be expected. Although the exact volume of soil to be removed from contaminated properties cannot be estimated at this time, the risks do not increase in direct proportion to the volume of the soil. Gamma radiation near the center of a storage pile could not travel more than several feet, and would be prevented from escaping by surrounding materials. Only the pile's outer layer of soil would give off gamma radiation that could successfully penetrate a cover and escape the pile to possibly cause risk to people nearby. The level of people's exposure would increase, but not as much as the volume of soil increases. The level of risk to people from a temporary storage pile would be related both to how close the edge of the pile is to property boundaries and how the materials are piled.

Some people may be concerned that only the additional, incremental risk from a new storage pile at the factory site was calculated, and not the total risk due to all the other materials already located at the factory site. This limitation is related to the purpose of the focused risk assessment. The purpose of this portion of the study was not to calculate current risks to residents living near the factory site, but only to determine whether adding additional material to the factory site on a temporary basis would significantly increase the cancer risks to nearby residents.

FOCUSED RISK ASSESSMENT FOR WEST CHICAGO VICINITY PROPERTIES

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EXECUTIVE SUMMARY

From approximately 1930 until 1958, the Lindsay Light and Chemical Company extracted thorium and other elements from monazite sands for the production of gaslights (lantern mantles) and hydrofluoric acid at a facility located at 783 Factory Street in West Chicago, Illinois. The refining processes used for monazite yielded radioactive tailings, primarily thorium (Th-232) and also residual levels of radium (Ra-226, Ra-228). Prior to Atomic Energy Commission (AEC) licensing requirements, much of the tailings material was disposed of in the local municipal park and municipal sewage treatment plant or used as fill material at residential and other properties throughout incorporated and unincorporated West Chicago. Due to the long half-life (greater than 14 billion years) of Th-232, the residues disposed of at these sites will retain their radioactive properties essentially forever.

Lindsay Light and Chemical Company was purchased by American Potash and Chemical Company in 1958. American Potash continued thorium production, and in 1967 was purchased by Kerr-McGee Chemical Corporation. The plant was operated as the Kerr-McGee Rare Earths Facility (REF) until its closure in 1973.

Studies sponsored and conducted by the United States Nuclear Regulatory Commission (USNRC), the United States Environmental Protection Agency (USEPA), and the City of West Chicago during the late 1970s and 1980s identified the following sites containing thorium residuals: a city park known as Reed-Keppler Park (RKP) and the West Chicago Sewage Treatment Plant (STP), each of which contained about 10,000 cubic yards of thorium residuals; a contaminated creek and river (Kress Creek and the West Branch of the DuPage River); and over 100 residential or commercial properties. These off-site properties have been listed on the National Priorities List (NPL) by the U.S. Environmental Protection Agency (EPA).

In 1984, Kerr-McGee and the City of West Chicago began a voluntary residential clean-up program, remediating the most highly contaminated properties in the incorporated areas of West Chicago. The removed thorium residuals were placed at the REF site. However, not all properties that exceeded the company's clean-up level were remediated. Therefore, thorium residuals still exist throughout the area in deposits both above and below 30 uR/hr at 1 meter, the level established by Kerr-McGee to initiate clean-up. Thorium residuals from decades of production also still exist in mill tailing piles at the REF factory site.

An aerial radiological survey of West Chicago conducted in 1989 by EG&G and ground level verification surveys conducted by the Illinois Department of Nuclear Safety (IDNS) have identified several new thorium anomalies. The identification of these sites, coupled with Kerr-McGee's petition to the USNRC for permanent disposal of the thorium residuals at the factory site, has brought new attention to the radioactive contamination problem in West Chicago.

This report presents the results of the focused risk assessments provided in support of removal actions under consideration at a number of private residences and schools in and around West Chicago. Specifically, this report utilizes data from three school properties and four residences sampled by IDNS.

This report is not intended to represent a Baseline Risk Assessment, which is USEPA's most comprehensive estimate of site-related risks. This report is a focused risk assessment, which assesses the general level of risk on several contaminated properties and the potential risk of placing contaminated soils on the factory site for interim storage. For this focused risk assessment, USEPA utilized data provided by IDNS for several properties. These data had been gathered by IDNS for its own surveillance purposes. USEPA believes that these data, while limited, are adequate for projecting general risk levels on the contaminated properties.

This report is divided into two parts. Part I presents current and potential future health risks associated with present levels of contamination for each of the seven properties. Part II presents the doses and health risks associated with the option of placing the remediated soil in a storage pile at the REF until a permanent disposal site is found.

In Part one, the following exposure pathways are considered for each of the properties:

1. External gamma radiation, both outside and inside structures.
2. Ingestion of vegetables and fruit grown in contaminated soil.
3. Direct ingestion of contaminated soil by children and adults.
4. Inhalation of contaminated soil that has been suspended by mechanical action or wind.
5. Inhalation of radon (Rn-222) and thoron (Rn-220) progeny due to residences built over contamination.

The present use scenarios assume current utilization of each property, structure, and location of contaminated areas. No significant amount of contamination has been found under the designated homes or schools. Therefore, the present land use risks are primarily limited to scenarios for exposures outside of structures. Extensive gardening is assumed to take place on the residential properties in the contaminated soil. The future use scenarios assume that, on each property, a home is built over the contaminated soil; therefore, indoor exposure scenarios are used. Fruit and vegetables are assumed to be grown in the contamination. Risks are calculated for both students and teachers at the schools. The scenarios for residences include both children and adults.

The risk assessments are based on school attendance durations of 2 to 4 years for children, 25 years for teachers and a 30-year occupancy time for residences. The exposure scenarios apply applicable exposure parameters from EPA guidance documents (EP89a, EPA89b, and EPA91). The EPA risk parameters or slope factors from the "Health Effects Assessment Summary Tables" (HEAST) (EPA92) are generally used to determine the health risks for total cancers (incidence including mortality).

The present use risks for the schools are an average of about 2 per 100,000 (2E-5) for students and 5 per 100,000 (5E-5) for teachers based on contamination levels of 3 to 35 pCi/g of Th-232. The risks for future unrestricted land use at these locations is about 7 per 1,000 (7E-3).

The health risk assessments for the four residences indicate that the average present land use risks are about 1 per 1,000 (1E-3). The risks for future unrestricted land uses are projected to be much higher because it is assumed that residences are built over existing contamination. These risks for future conditions at the specified residences range from about 6 per 1,000 (6E-3) to up to 9 per 100 (9E-2).

Part II of this report analyzes the doses and risks associated with the storage of excavated soil at the Rare Earths Facility factory site. The assessments are based on the volume of soil and radionuclide concentrations resulting from the excavation of the contaminated soil at the properties described in Part I. The analyses are limited to direct radiation since the waste pile is assumed to be covered, thereby eliminating radon and thoron emanation and the suspension of particulates.

The contaminated soil is assumed to be placed in a pile such that its edge would be located approximately 50 feet from the west property fence line which boarders the Elgin, Joliet, and Eastern Railroad tracks. A person standing at a distance of 1 ft from the storage pile would be exposed at a rate of about 32 μR/hr above background. This is about five times the exposure rate from natural external background radiation (approximately 7 μR/hr). For each hour at the site in close proximity to the storage pile, the person's potential lifetime risk of cancer due to this exposure is about 2 per 100,000,000 (2E-8).

The exposure rate from the contaminated dirt drops to approximately 7 μR/hr, a rate comparable to normal background, at about 28 feet from the pile. When total radiation levels are less than twice background, it becomes difficult to detect elevated radiation levels using conventional survey meters. Thus, at approximately 28 feet from the pile, it would be difficult to discern the elevated exposure resulting from the pile.

The ability to detect elevated external gamma exposure rates due to the presence of the new storage pile is complicated by the generally elevated background levels at the facility in the area where the pile is to be placed due to the presence of old tailings piles and other contamination from past activities. At the west fence line, the preexisting exposure rates range from 39 to 110 μR/hr. The new pile would add about 4 μR/hr, an increase in the existing exposure rates of 5 to 10 percent which would be marginally discernable using conventional survey meters. The total health risk associated with an exposure rate of 4 μR/hr is an incremental increase in the lifetime risk of cancer of 25 per 1,000,000,000 (2.5E-9) for every hour of exposure.

The distance from the edge of the proposed storage pile to the nearest resident is approximately 400 feet. At that distance, the unshielded exposure rate from the new pile would be 0.1 μR/hr, a rate which would not be discernable from background. Assuming that the resident is home for 75 percent of the day for 350 days each year, that 0.5 hours a day are spent outside the residence, and that exposures inside the residence are less than those received outside by a factor of 0.8, the annual dose to the resident would be 0.53 mrem. At an annual dose rate of 0.53 mrem/yr for 30 years, the incremental increase in the lifetime risk of cancer is 1 in 100,000 or 1E-5.

The lifetime total risk of cancer due to external exposures from the new storage pile is less than 1 in 1,000,000 (1E-6), the point of departure for determining remediation goals, at a distance of about 900 feet. The total exposure rate associated with this risk is 0.01 μR/hr. The annual dose equivalent rate at 900 feet is 0.052 mrem/yr.

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1. Introduction

1.1 BACKGROUND

From approximately 1930 until 1958, the Lindsay Light and Chemical Company operated a thorium extraction facility at 783 Factory Street in West Chicago, Illinois. During the 1930's and throughout World War II, the company extracted thorium and other elements from monazite sands for the production of gaslights (lantern mantles) and hydrofluoric acid. The General Services Administration also contracted for thorium as part of the Manhattan Project and later Atomic Energy Commission needs. The refining processes used for monazite yielded radioactive tailings, primarily thorium (Th-232) and also residual levels of radium (Ra-226, Ra-228). These tailings were initially stored at the factory site in tailings piles for settling ponds. However, prior to Atomic Energy Commission (AEC) licensing requirements, much of the tailings material was disposed of in the local municipal park and municipal sewage treatment plant or used as fill material at residential and other properties throughout incorporated and unincorporated West Chicago. Due to the long half-life (greater than 14 billion years) of Th-232, the residues disposed of at these sites will retain their radioactive properties essentially forever.

Lindsay Light and Chemical Company was purchased by American Potash and Chemical Company in 1958. American Potash continued thorium production, and in 1967 was purchased by Kerr-McGee Chemical Corporation. The plant was operated as the Kerr-McGee Rare Earths Facility (REF) until its closure in 1973.

Several studies, sponsored by the United States Nuclear Regulatory Commission (USNRC), the United States Environmental Protection Agency (USEPA), and the City of West Chicago were conducted during the late 1970s and 1980s. These studies identified the following sites containing thorium residuals: a city park known as Reed-Keppler Park (RKP) and the West Chicago Sewage Treatment Plant (STP), each of which contained about 10,000 cubic yards of thorium residuals; a contaminated creek and river (Kress Creek and the West Branch of the DuPage River); and over 100 residential or commercial properties. Figure 1-1 shows the location of these sites with respect to the REF.

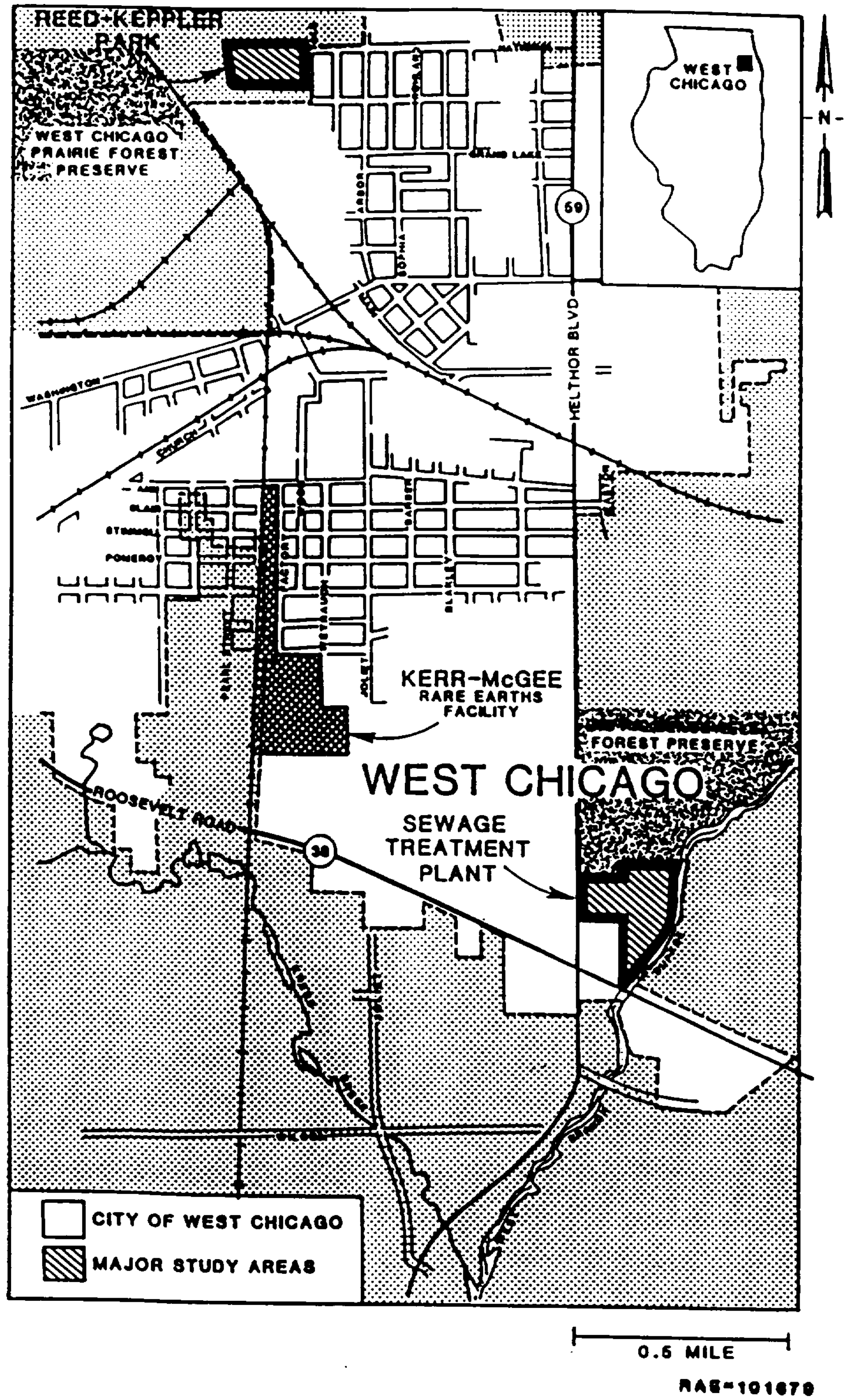

Figure 1-1. Map of Area Surrounding the Kerr-McGee Rare Earths Facility in West Chicago, Illinois

Kress Creek became contaminated because, over the years, it received runoff and waste water from the REF site. The contamination then moved downstream and into the West Branch of the DuPage River.

In September 1977, EG&G Aerial Measurements conducted an aerial radiological survey of the West Chicago area for the USNRC. This survey identified several areas exhibiting elevated gamma radiation levels (radiological anomalies) in and around West Chicago, including sites at RKP, the STP, Kress Creek and a number of residential properties. Subsequent to surveys conducted by the USNRC and the City, Kerr-McGee conducted radiation surveys throughout the city and identified 117 properties with radiation exposure rates exceeding 30 uR/hr at 1 meter, the level established at that time by the company to initiate clean-up.

In 1984, Kerr-McGee and the City of West Chicago began a voluntary residential clean-up program, remediating the most highly contaminated properties in the incorporated areas of West Chicago. The thorium residuals that were removed from the residential properties were placed at the REF site. However, not all properties that exceeded the company's clean-up level were remediated. Therefore, thorium residuals still exist throughout the area in deposits both above and below the level established by Kerr-McGee for clean-up. In addition, thorium residuals from decades of production still exist in mill tailing piles at the REF factory site.

In June 1989, a second aerial radiological survey of West Chicago was conducted by EG&G for the Illinois Department of Nuclear Safety (IDNS). As a result of this survey and ground level verification surveys conducted by IDNS, several new thorium anomalies were identified. The identification of these sites, coupled with Kerr-McGee's petition to the USNRC for permanent disposal of the thorium residuals at the factory site, brought new attention to the radioactive contamination problem in West Chicago.

The state of Illinois petitioned the NRC for amendment of the agreement state licensing program to include licensing control of the material (11e.(2) by-product) at the Kerr-McGee site. IDNS was granted licensing authority, effective November 1, 1990. During the spring of 1990, in preparation for gaining licensing control, IDNS expanded its environmental monitoring program in and around West Chicago. This expansion included radon/thoron and air particulate evaluations at several of the local schools.

Also, at the request of the school districts, IDNS conducted radiological surveys of seven school properties.

In October 1984, the USEPA placed four sites on the Proposed National Priorities List (NPL): the "residential areas" in West Chicago and DuPage County, Reed-Keppler Park, the Sewage Treatment Plant, and Kress Creek/West Branch of the DuPage River. Three of the sites were placed on the Final NPL in August 1990. The fourth was placed on the Final NPL in February 1991. These four sites are therefore eligible for remediation under USEPA's "Superfund" program. The REF factory site is under the jurisdiction of the IDNS, and has not been placed on the NPL.

1.2 PURPOSE AND SCOPE OF THIS REPORT

In recent years, over 50 new contaminated properties have been found in the city of West Chicago and unincorporated DuPage County. This report presents the results of focused risk assessments prepared in support of removal actions under consideration at a number of private residences and schools in and around West Chicago. The report specifically addresses three school properties and four residences that were identified and sampled by IDNS.

This report is not intended to represent a Baseline Risk Assessment, which is USEPA's most comprehensive estimate of site-related risks. A Baseline Risk Assessment typically is prepared near the end of the Remedial Investigation, after extensive data has been gathered for the purpose of supporting a Baseline Risk Assessment. This report is a focused risk assessment which assesses the general level of risk on several contaminated properties, and the potential risk of placing contaminated soils on the factory site for interim storage. For this focused risk assessment, USEPA utilized data provided by IDNS from several properties. IDNS had gathered the data for its own surveillance purposes. USEPA believes the data is adequate for projecting general risk levels on the contaminated properties and for estimating the risk of placing contaminated materials on the factory site for interim storage.

USEPA recognized that there would be difficulties in projecting risks from limited data. Therefore, USEPA sought to balance some of the conservative assumptions that were made in this report with realistic adjustment factors. For example, typically only one soil sample was taken from each property, from the area with the highest outdoor gamma exposure rate measurement. While the soil concentration obtained from that single soil sample was assumed to apply uniformly to the contaminated area on that property (a conservative assumption), USEPA used adjustment factors, where appropriate, to reduce exposure for certain exposure pathways depending upon the characteristics of that property.

USEPA recognizes that some conservative assumptions were made regarding the contamination on the properties examined in this report, so the projected risk levels for those properties may be conservative. However, it also must be recognized that the residential properties in this report had relatively small areas of contamination compared to the size of the entire property. It is likely that there are other residential properties, not included in this report, that have areas of contamination covering a much larger portion of the property. Therefore, the assumptions made in this report may be conservative for some properties but realistic for other properties. Moreover, the range of concentrations used probably will cover most of the concentrations to be encountered when cleanup begins.

This report is divided into two parts. For each property, Part I presents current and potential future health risks associated with present levels of contamination. Part II presents the doses and health risks associated with the option of placing the remediated soil in a storage pile at the Rare Earths Facility (REF) until a permanent disposal site is found and the material is removed from the REF.

The primary concerns of Part I are the health risks associated with residual levels of radionuclide contamination at the selected private properties and schools. The analyses address the risks at the various properties associated with the current levels of contamination and usage of the properties. The Part I analyses also address how risks may change assuming the current usage of these properties changes in the future. For example, although a given property may not currently be used for gardening or have a house on it, it may in the future. Therefore, Part I evaluates the risks under such future use scenarios.

In Part I, the risk assessments are based on radiological survey and sampling data obtained by IDNS during the identification of the properties and initial site surveys. This radiological survey information is generally limited to one soil sample per property and a survey of the property with portable radiation measurement instruments. Even though complete surveys of each property were performed, generally only the peak or maximum survey measurements have been reported. Soil samples were taken at the location of peak gamma survey results. When performing these risk assessments, concentrations derived from these samples were conservatively assumed to apply uniformly to the entire contaminated area.

Part II of this report analyzes the doses and risks associated with the storage of excavated soil at the Rare Earths Facility factory site. This analysis is performed because it is recognized that a new pile of contaminated soil, if placed in storage at the REF next to the existing piles, may increase the radiation field in the vicinity of those piles, thereby offsetting some of the benefits associated with excavating the soil. Accordingly, the purpose of the Part II analysis is to determine the magnitude of the exposures associated with placing the excavated soil in storage at the REF.

In Part II, the dose and risk assessments from the storage pile are based on the volume of soil and radionuclide concentrations resulting from the excavation of the contaminated soil at the properties described in Part I. The analyses are limited to direct radiation since the waste pile is assumed to be covered, thereby eliminating the radon and thoron emanation and the suspension of particulates. Inadvertent intrusion scenarios are not addressed since it is assumed that the storage area will be under continual institutional control until a permanent disposal site is found and the material is removed from the REF.

2. Part I: Assessment of Risks Associated with Residual Radioactivity in Soil

This part of the focused risk assessment presents a quantitative assessment of the potential health risks to individuals associated with residual levels of radioactivity at 3 schools and 4 residences in the vicinity of West Chicago.

2.1 RISK ASSESSMENT PROCEDURES

The risk assessments have been performed using standard state-of-the-art pathway and risk assessment models. The pathway models are similar to those used by the EPA PATHRAE code (Ro87) and those in the Superfund Exposure Assessment Manual (EPA89d). The pathway calculations are based on exposure factors from the EPA "Exposure Factors Handbook" and the Risk Assessment Guidance for Superfund (EPA89a, EPA89b, EPA91). The health effects estimates are based on the slope factors from the "Health Effects Assessment Summary Tables" (HEAST) (EPA92). These health effects are for total cancers, including both mortality and morbidity (EPA92).

The subject properties include both schools and private residences. Risk assessment results are presented for present land use conditions and potential unrestricted future land uses using current levels of contamination. With the exception of Residence 4, the contamination at the locations covered by the present land use assessments are not associated with structures. Therefore, the risks for present land uses focus on exposures associated with outside activities. The risks for future land use include the potential of residences being built over the contaminated locations. Therefore, the assessments for projected future land uses include risks from exposures that occur both inside and outside of residences.

In order to accurately assess risks at the properties contaminated with materials from the Rare Earths Facility, both gamma measurements and soil concentration data are necessary. However, extensive data has not yet been collected at most of these properties, and information on concentrations of soil contamination is limited. The properties evaluated in these risk assessments were selected by EPA based on the amount of usable data available (i.e., both gamma measurements and soil concentration data were available).

The characteristics of the contaminants are described in Section 2.1.1. The characteristics of the population groups considered to be present at the schools and residences are discussed in Section 2.1.2. The schools included in this analysis are a preschool, junior high, and high school. Specific exposure scenarios are presented for each school. The scenarios for schools and residences include both children and adults. Site characteristics are described in Section 2.1.3, and exposure pathways are described in Section 2.1.4.

The exposure pathways considered are:

1. External gamma radiation, both outside and inside structures.

2. Ingestion of vegetables and fruit grown in contaminated soil.

3. Direct ingestion of contaminated soil by children and adults.

4. Inhalation of contaminated soil that has been suspended by mechanical action or wind.

5. Inhalation of radon (Rn-222) and thoron (Rn-220) progeny due to residences built over contamination.

The present use scenarios assume current utilization of each property, structures, and locations of contaminated areas. Extensive gardening is assumed to take place on the residential properties in the contaminated soil. The future use scenarios assume that, on each property, a home is built over the contaminated soil and fruit and vegetables are grown in the contamination. There is little if any fruit grown in the area, but this pathway was included to provide a comprehensive assessment and to account for possible future land uses. There is no dairy farming or production of beef in the area; therefore, these pathways have not been included. Based on the small areas of contamination, limited depths of contamination, and low environmental mobility of thorium and its progeny, a specific groundwater contamination scenario has not been presented. The exclusion of the groundwater scenario is supported by the fact that where groundwater data are available for residential sites, no evidence of thorium/progeny contamination exists.

2.1.1 Nature of the Contaminants

Ore residuals from the West Chicago Rare Earths Facility used at the off-site areas contained Th-232 and its progeny and lesser amounts of U-238 and its progeny. Figures 2-1 and 2-2 present the decay chains for Th-232 and U-238, respectively. The analytical procedures used to characterize the contamination at the Rare Earths Facility and off-site properties have generally focused on specifying the quantities of Th-232 and Ra-226, a progeny of U-238. Since U-238 was initially present in the ore processed at the facility and there is no evidence that it is not present in the off-site properties ore residuals, it is assumed that U-238 and the intermediate progeny prior to Ra-226 are also present. In subsequent sections of this report, it is assumed that the concentrations of U-238 are equal to the reported values for Ra-226.

The prior site characterization work (EPA86) indicated that the concentrations of Th-232 and its progeny are about ten times the concentrations of U-238 and its progeny. This ratio of ten is also supported by information reported by the Illinois Department of Nuclear Safety (IDNS91) for the schools included in this assessment and the limited data from the residences included in this assessment. Therefore, in this assessment, the concentrations for Th-232 are ten times those used for U-238. Both Th-232 and U-238 are assumed to be in secular equilibrium with their progeny. That is, the activity of each progeny equals the activity of the parent.

There are noble gas radioactive progeny from both the Th-232 and U-238 decay chains. These noble gases diffuse from the source material and may result in radiation exposure to people through the inhalation pathway. Radon-222, a decay product of Ra-226 from the U-238 decay chain, is commonly called radon. It will be referred to as radon or Rn-222 in this assessment. Radon-220, a decay product related to Ra-228 in the Th-232 decay chain, has historically been referred to as thoron. The radiation dose from both radon and thoron is due to their short half-life radioactive progeny. The primary risk from radon and thoron progeny is from exposure to concentrations that occur when progeny accumulate in structures having limited air exchange rates. Therefore, buildings which are generally closed because of air conditioning and heating provide the "indoor exposure scenario."

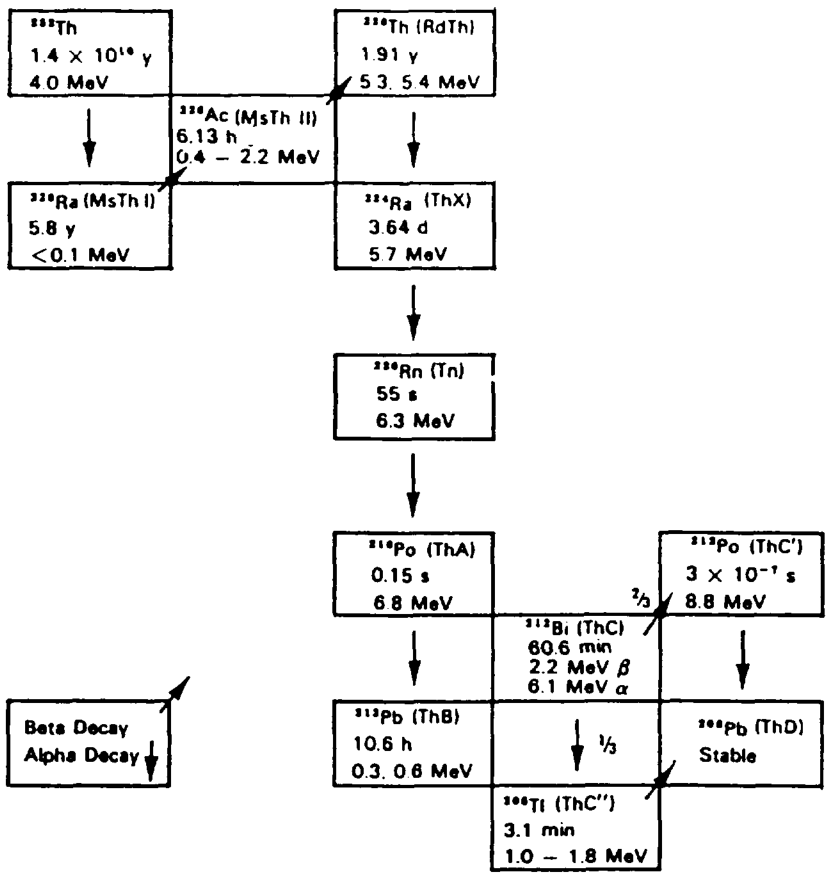

Figure 2-1. Th-232 Decay Chain

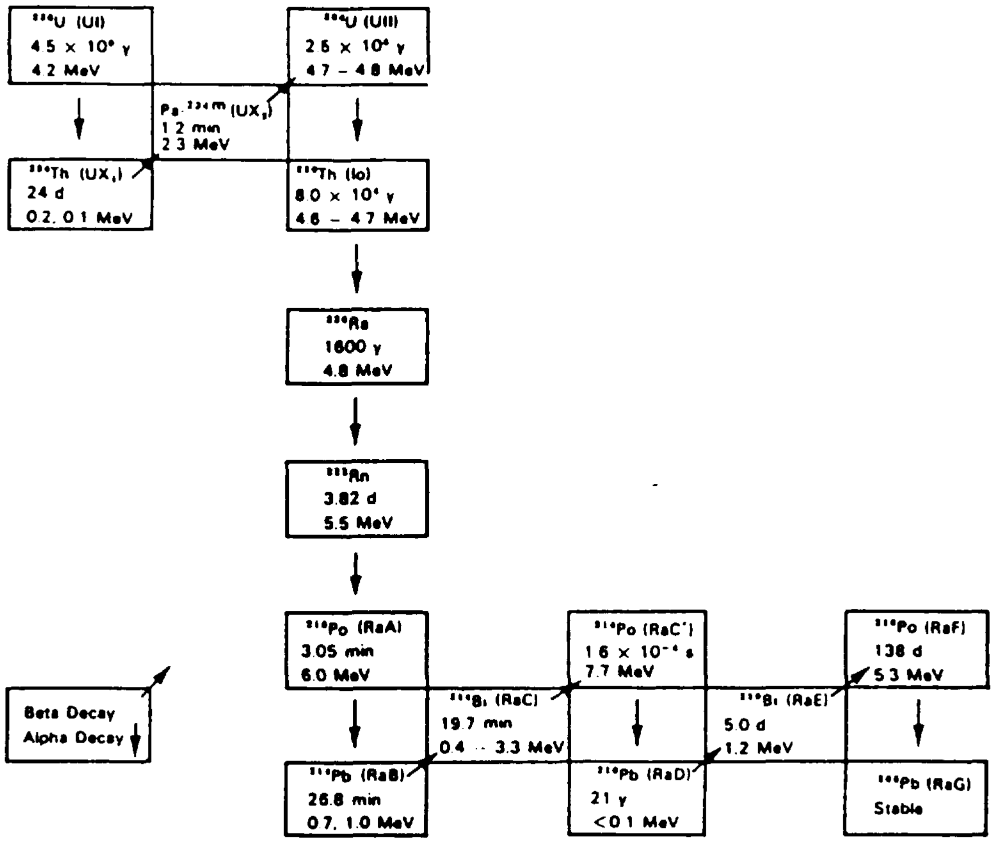

Figure 2-2. U-238 Decay Chain

The model used to assess the indoor thoron/radon exposures is assumed to be a heated and air conditioned home with a crawl space located over the contaminated area. Assuming a structure with a crawl space versus one with a concrete basement or slab-on-grade construction maximizes the potential exposure to thoron. This is because thoron, with its short half-life, decays before it can diffuse through concrete. The model for diffusion of radon and thoron into the crawl space and from there into the home is taken from the Remedial Investigation Report (EPA86). The model and parameters for the calculations are given in Appendix A.

2.1.2 Population Characteristics Used for Risk Assessments

The age (child, teenage, or adult) of the populations assumed to be present at the different locations and the time parameters that define the duration of exposure for the different scenarios are given in Table 2-1. The basic population groups are students and teachers at the schools and children and adults at the residences. The scenario for future unrestricted land use assumes that old buildings are removed and new residences are built over the contaminated areas on all seven properties. Therefore, the population for unrestricted future land use at all locations is the same as that assumed for the present use residences. The object of this analysis is to use reasonable parameters to characterize the maximum exposed individuals for the time period that they are either attending the school or living at the residences. The parameters for residences are based on values generally used for EPA risk assessments (EPA89a, EPA89b, EPA91).

The age distributions for the students are children 1 to 5 years of age for the preschool, and teenagers for the junior and high schools. The definition of children is taken as age 0 to six years of age. The years of exposure for each age group are given in Table 2-1. Preschool students are assumed to be present between the age of 1 and 5 years, for a total of 4 years (judged to be conservative). Junior high, for the subject school, is the seventh and eighth grades. Therefore, an exposure period of 2 years was used. The subject high school includes grades ninth through twelfth. Thus an exposure period of 4 years was used. Teachers are assumed to work at the school for a 25-year period.

Exposure periods in terms of hours per day, days per week, and weeks per year are also given in Table 2-1. The exposure periods of 2 and 3 hours per day used for the schools and the associated frequencies related to days per year are based on projections for relevant school students and the climate (extreme winters) of West Chicago.

Table 2-1. Scenarios and Exposed Populations

Locations	Exposure Times: Child[a] (Years)	Exposure Times: Teen (Years)	Exposure Times: Adult (Years)	Outside Hours/Day	Inside Hours/Day	Days Per Week	Weeks Per Year
Schools							
#1: PreSchool							
Present Use	4	NA	25	2	(b)	5	39
Future Use[c]	6	NA	24[d]	0.5	18	7	50
#2: Junior High							
Present Use	NA	2	25	3	(b)	5	26
Future Use[c]	6	NA	24[d]	0.5	18	7	50
#3: Senior High							
Present Use	NA	4	25	3	(b)	5	26
Future Use[c]	6	NA	24[d]	0.5	18	7	50
Residences							
Present Use	6	NA	24[d]	0.5	(b)	7	50
Future Baseline[c]	6	NA	24[d]	0.5	18	7	50

NA Not applicable. The teenage scenario is only used for the junior and senior high schools.
(a) A child is age 0 to 6 years old. The preschool age group is taken as 1 to 5 years old.
(b) Contamination has not been found under existing structures, except for a small amount near Residence #4 where an 18 hour per day exposure time is assumed.
(c) Future use is assumed to be unrestricted use, with the building of residences over contaminated areas.
(d) The maximum residence time used is 30 years, with 6 years spent as a child.

The maximum exposed individual for residences is taken to be a person present for 30 years. For the soil ingestion scenario, this person has the characteristics of a child for ages 0 to 6 year. Adult parameters are used for the remaining 24 years. Adult parameters are used when evaluating all other exposure pathways at a residence.

For residences, an exposure-year is considered to be 350 days (EPA89a, EPA91). The 350-day year is based on an average of 15 days (e.g., vacation, etc.) away from a residence. Inside exposures to external gamma, radon, thoron and the progeny are based on a 75 percent occupancy factor (i.e., EPA factor for indoor radon) (EPA91) for 350 days of each year. The outside external gamma dose is based on exposure for 0.5 hr per day or 3.5 hours per week for the 350-day year (EPA91). The remainder of the day, 5.5 hours, is assumed to be spent away from the subject residence. The time spent away from the residence is not equal to a normal 8-hour work day (could also include transportation time), but the most highly exposed individual at the residence may not work away from the home. Occupancy scenarios include home makers who may spend most of their time at home, and people who work at home. In summary, the average residency year, for the most highly exposed person at a location, is assumed to be 350 days, with 75 percent of this time (18 hours per day) spent inside and 0.5 hours per day (2.08 percent) spent outside, with the remaining 5.5 hours per day spent away from the property. These occupancy time factors are based on references EPA89b, EPA91, and EPA89c.

The future use scenario assumes a residence is constructed over the contamination. This scenario results in the greatest potential reasonable risk. The period of residency is taken as 30 years (EPA91a), the maximum period of time generally spent at one residence in the U.S. For the soil ingestion scenario, the characteristics of a child are used for ages 0 to 6 years. Adult parameters are used for the remaining 24 years. Adult parameters are used when evaluating all other exposure pathways at a residence.

2.1.3 Site Characteristics

As stated previously, in recent years over 50 new sites of contamination have been found in the area around the Rare Earths Facility. The surveys of the West Chicago area include a survey by the Illinois Department of Nuclear Safety of public schools (IDNS) (IDNS91). The IDNS identified several schools with contamination. EPA selected three of the school properties and four residences identified by IDNS for assessment. The radiological monitoring information for these properties is based on the IDNS survey (IDNS91) and the property surveys. The information on these sites is summarized in Table 2-2. The subset of locations for School No. 3 and Residence No. 4 are identified by alphabetical suffixes which reflect different areas of contamination on these properties.

Samples from the area where the maximum external gamma measurements were observed at two of the schools indicated 3 pCi/g of Th-232 (see Table 2-2). The third school has four areas of contamination that are greater than 30 pCi/g of Th-232. The total area of contamination for this school is about 90,000 square feet. Approximately 17,000 square feet of this is covered by asphalt.

The four residential properties had smaller areas of contamination, but the concentrations of Th-232 were higher. The sample from Residence No. 4 indicated concentrations of 780 pCi Ra-228/g in an area of 1,350 square feet. Ninety percent of this area is covered by asphalt. Samples from the other residences have concentrations of 28 pCi, 200 pCi and 490 pCi of Ra-228 per gram of soil and each had about 2,200 square feet of contaminated area. One of the areas is covered by asphalt. All residences had external gamma exposures greater than 50 μR/hr above natural background (which is about 7μR/hr) one meter above the contaminated surfaces. Table 2-2 gives site-specific data for the properties.

The concentration of contaminants were generally based on detection of Ra-228 (generally Ac-228) in soil samples. Samples were not analyzed for Th-232. Based on the absence of information to the contrary, it is assumed that all radioactive progeny of the Th-232 chain are present in equilibrium. Based on available measurements and former assessments, it is assumed the U-238 concentrations are 0.1 of the Th-232 concentrations. The Th-232 to U-238 ratio is based on the RI (EPA86) and is supported by the analysis of samples for the properties addressed in this report. The data in the RI (EPA86) is primarily based on samples from the Rare Earths Facility and ore residuals that were transported to the West Chicago Sewage Treatment Plant. The RI data base included samples which had been analyzed by EPA laboratories, independent commercial laboratories, and Kerr-McGee. The data base for the present residential properties (listed in Table 2-3) is based on analysis by the Illinois Department of Nuclear Safety. These samples were analyzed by gamma spectroscopy, and results were reported for Ac-228 (a progeny of Ra-228) and the progeny of Ra-226 (a progeny of U-238).

Table 2-2. Site Characterization Data, West Chicago Properties

ID Code	Th-232* (pCi/g)	Ext. Gamma# (microR/Hr)	Source Description Width (ft)	Length (ft)	Depth (ft)	Area (sq ft)	Volume (cu ft)	Surface Material
Schools##								
1-Preschool	3	8	80	100	2	8,000	16,000	soil
2-Jr. High	3	3	175	320	2	56,000	112,000	soil
3-Senior High-A	34	11	spots		2	1,200	2,400	soil
3-Senior High-B	34	4	spots		2	790	1,580	soil
3-Senior High-C	35	10	130	130	2	17,000	33,800	asphalt
3-Senior High-D	35	10	100	700	1	70,000	50,000	soil
Residences								
4-A	780	590	20	60	1	1,200	1,200	asphalt
4-B	780	590	10	15	1	150	150	soil
5	490	52	40	60	2	2,400	4,800	soil
6	200	52	30	70	1	2,100	2,100	asphalt
7	28	92	40	50	1	2,000	2,000	soil

* All progeny of Th-232 and U-238 are assumed to be in secular equalibrium with the head of their respective chains. U-238 concentrations are 10 percent of those for Th-232. Sample locations are not precisely indicated in IDNS91. However, no samples appear to have been taken under asphalt.

\# Net exposure rate.

\## The suffixes represent different areas of contamination on the same properties.

Table 2-3. Exposure Pathways

	Population			Exposure Scenarios						
				External Gamma				Inhalation		
									Radioactive Gases	
Locations	Child	Teen	Adult	Outside	Inside	Ingestion of Soil	Ingestion Veg/Fruit	Airborne Soil Particulates	Radon	Thoron
Schools										
#1: PreSchool										
Present Use	X	NA	X	X	(a)	X	NA	X	NA	NA
Future Use	X	NA	X	X	X	X	X	X	X	X
#2: Junior High										
Present Use	NA	X	X	X	(a)	X	NA	X	NA	NA
Future Use	X	NA	X	X	X	X	X	X	X	X
#3: Senior High										
Present Use	NA	X	X	X	(a)	X	NA	X	NA	NA
Future Use	X	NA	X	X	X	X	X	X	X	X
Residences										
Present Use	X	NA	X	X	(a)	X	X	X	NA	NA
Future Use	X	NA	X	X	X	X	X	X	X	X

NA Not applicable.
(a) There is no indication of contamination under the present buildings.

2.1.4 Exposure Pathways

The exposure pathways used for the scenarios at the properties are identified in Table 2-3. Note that, in the analysis, the risks to students and teachers are kept separate from the residential risks. This is done in order to reveal incremental risks from the residual contamination at the schools. In theory, the students and teachers who are exposed at school may also be exposed from residual radioactivity at their residences.

The pathway of external gamma radiation is due to the radiation is emitted from the contaminants in the soil that results in direct exposure to people in the area of the contamination. Gamma radiation from contaminants under structures can also pass through the floor of the structure (there is some attenuation) and produce direct gamma exposure to people in the structure. The pathways of ingestion and inhalation are due to intakes of radioactive material due to migration or transport of radioactive material to people. These transport/migration routes are:

- Direct ingestion of small quantities of contaminated soil due to contact of food, a persons hands, or other materials with the soil.
- Ingestion of food products, which have incorporated radioactive material due to being grown in the contaminated soil.
- Resuspension of contaminated soil and inhalation of gases that diffuse from the contaminated soil.

The present use scenarios for the residences include the pathways of ingestion of vegetables and fruit grown on the site. The present use scenarios for the schools do not include food pathways. The vegetable ingestion scenarios are based on 40 percent of the critical individuals diet of vegetables being grown in the contaminated area (EPA89a). The fruit scenario is based on 30 percent of a person's diet of fruit being grown in the contaminated area (EPA89a). The areas of contamination are indicated in Table 2-2 in Section 2.1.3. In some cases, the contaminated areas are a small fraction of the lot size needed to produce a significant portion of the fruit, vegetables, and grain used by an average size family. A lot size of about 22,000 square feet or about one-half acre is needed to provide a significant fraction of the home grown produce consumed by a family. Therefore, these generic ingestion usage factors have been adjusted for the different properties, based on the size of the contaminated area of the property. These exposure adjustment factors are presented in Table B-6 of Appendix B. The presence or absence of fruit growing has not been documented in the site characterization reports. Apparently, there is little if any fruit grown in the area. However, although it may be conservative, growing of fruit has been included since it is not unreasonable to assume that it could occur.

Assessments are provided for present land use and for unrestricted future land use. The present use scenarios are based on the current locations of buildings and the contaminated areas, the presence of surface coverings of asphalt or concrete over the contaminated areas, and the relative sizes of the contaminated areas. The external gamma assessments for present use scenarios are based on the net (i.e., measurement minus natural background) exposure measurements reported for the site. Generally the reported measurements, which were the maximum measurement at the sites, reflect a conservative value. The contaminated areas are generally not associated with the present buildings at the sites. Therefore, the scenarios for present uses do not include the pathways of indoor thoron and radon, or indoor gamma exposure for most of the sites. There is a contaminated area near the residence for Location 4, and the indoor inhalation pathway is included for present use status for this location. This exposure for Residence No. 4 is estimated to be about 10 percent of that which would be received if the residence were located completely over similar contaminated materials.

The exposure scenarios for these assessments were developed to provide conservative, but generally reasonable, exposure conditions based on the property assessment reports. Complete gamma surveys were apparently performed at each property, and the indication of the presence of contamination and the soil sampling were based on the gamma surveys. However, the complete gamma survey information was not available for these assessments.

The future use scenarios are based on future unrestricted use of each of the properties as residences. Although buildings are not presently located over contamination today, it is assumed that a residence with a crawl space is built over the contamination in the future. An occupancy factor of 75 percent is used for the postulated residence, reduced by the ratio of a 350-day year at home versus 365 days (e.g., two-week vacation away from home). Indoor exposure scenarios include exposure to gamma radiation and inhalation of thoron and radon progeny. The indoor thoron/radon scenario is described in Appendix A. The indoor gamma exposure includes the shielding effect of a 2 inch thick wood floor (i.e., reduction to 75 percent of unshielded exposure). The gamma exposures were calculated using the MicroShield computer code (Grove Engineering, Maryland), based on the Th-232 and U-238 concentrations in the contamination and shielding due to the wood floor or over-burden soil as appropriate.

Fluxes of radon and thoron released from the contaminated materials are based on assessments and measurements presented in the RI (EPA86), work by Strander (St80) and Zarcone et al. (Za86), and modeling of the flux. Flux estimates of 0.28 pCi/m^2-sec of radon and 30 pCi/m^2-sec of thoron per pCi/g of U-238 and Th-232, respectively, were used in the RI (EPA86). However, these values were based on measurements from moist soil and modeled the release of radon and thoron from relatively moist soil (EPA86). The soil in the crawl space under a building will be dry and have a higher relative flux. The fluxes used for these assessments are 0.4 pCi/m^2-sec of radon per pCi/g of Ra-226 and 90 pCi/m^2-sec of thoron per pCi/g of Th-232 in the soil. These fluxes generally reflect an effective diffusion coefficient for the soil of 0.05 cm^2-sec and an emanating power of 20 percent.

2.1.5 Risk Parameters

The risk parameters or "slope factors" of the HEAST tables (EPA92) were used to determine risks based on the radiation exposures to the contaminants for the inhalation and ingestion pathways. These health effects, which are for total cancers, include both incidence and mortality (EPA92). However, the HEAST risk factors could not be readily used to determine the risks for the radon/thoron or external gamma exposures in this assessment. Therefore, supplemental information was used.

The radon risk is based on the risk assessment procedures proposed by the EPA Science Advisory Board in 1992. The risk parameter used is 224 per million WLM of exposure. The thoron risk value is 180 per million WLM of exposure (EPA86). These risk parameters are only for mortality and do not include morbidity. Inclusion of morbidity would increase the risk parameters by about 10 percent, since lung cancer has about a 90 percent fatality rate (Am91).

Health risks due to external gamma exposure were calculated using 6.23E-4 total cancers per rad (EPA89b). Approximately 60 percent of these cancers are fatal (EPA89b). It is assumed that one roentgen equals one rad equals one rem for the purpose of this study.

2.2 RADIOLOGICAL RISK ASSESSMENTS

Properties were selected by EPA for this assessment based on the availability of information. There have not been extensive site characterization surveys. The available data base is generally limited to screening surveys to identify the presence and general extent of contamination. Risk estimates are provided for the following scenarios:

- Present Status of Site:
  - Present Land Use
  - Unrestricted Future Land Use

The effort was to use upper-bound, but reasonable, parameters for the assessments. The basic assessment parameters are summarized in Table 2-4. The model for the radon and thoron assessment is given in Appendix A, and additional information on the risk assessment calculations for external gamma exposures and the pathways calculations are given in Appendix B.

2.2.1 Risks for Present Land Uses

The risks for present land uses are given in Table 2-5. The risks presented for the schools are for students attending the schools for the time period indicated. The risks presented for the residents are the risks due to an assumed 30 years of exposure, including 6 years as a child and 24 years as an adult. The population group assumed for the risk estimate is also given on the right. The risks for all the pathways, the assumptions, equations and the modifying factors used to correct for the small areas of contamination are given in Appendix B.

For children, the present land use risk at the preschool (School 1, Table 2-5) is about 1.8E-5[a] or about 2 per 100,000. The risks to teenagers at the junior high and high school are about 3.3E-6 and 2.4E-5, respectively. The risks to teachers at the three

[a] The number 1.8E-5 is equivalent to 1.8×10^{-5}.

Table 2-4. Risk Assessment Parameters

Location	People	(h/d)	(d/wk)	(wk/y)	(h/y)	(years)	Ingestion: Soil (mg/d)	Ingestion: Food Grown on Site: Vegetables (g/d)	Ingestion: Food Grown on Site: Fruit (g/d)	Inhalation Rate (m^3/h)
Schools										
Present Land Use at School #1										
	Child	2.0	5	39	390	4	200	NA	NA	(a)
	Teacher	2.0	5	39	390	25	50	NA	NA	1
Present Land Use at School #2										
	Teenager	3.0	5	26	390	2	100	NA	NA	1
	Teacher	3.0	5	26	390	25	50	NA	NA	1
Present Land Use at School #3										
	Teenager	3.0	5	26	390	4	100	NA	NA	1
	Teacher	3.0	5	26	390	25	50	NA	NA	1
Future Land Use										
	Child	0.5	7	50	175		200	NA	NA	NA
	Adult	0.5	7	50	175		100	200	140	1
Residences										
Present & Future Land Use										
	Child	0.5	7	50	175		200	NA	NA	NA
	Adult	0.5	7	50	175		100	200	140	1
Future Land Use										
Indoor Exposure Senarios		18	7	50	6,300		NA	NA	NA	NA

(a) The relative combination of inhalation and the reciprocal of body weight is similar to an adult and the adult values are used.
NA Not Applicable.

Table 2-5. Health Risks of Present Land Uses, West Chicago Off-site Properties

Location	Th-232[a] (pCi/g)	Soil Ingestion Risk	Ingestion Veg. & Fruit Risk	Inhalation of Particulates Risk	Inhalation of Th/Rn Risk	Total Inhalation & Ingestion Risk	Gamma Exposure Risk	Total Risk	Exposed Person
Schools - Children									
#1 Preschool	3	1.2E-07	NA[c]	9.7E-11	NA	1.2E-07	1.8E-05	1.8E-05	Child
#2 Jr. High	3	2.0E-08	NA	4.9E-11	NA	2.0E-08	3.2E-06	3.3E-06	Teen
#3 High School[f]	35	4.6E-07	NA	1.1E-09	NA	4.6E-07	2.4E-05	2.4E-05	Teen
3-A	34	4.4E-07	NA	1.1E-09	NA	4.4E-07	2.4E-05	2.4E-05	Teen
3-B	34	4.4E-07	NA	1.1E-09	NA	4.4E-07	8.6E-06	9.1E-06	Teen
3-C/D	35	4.6E-07	NA	1.1E-09	NA	4.6E-07	2.2E-05	2.2E-05	Teen
Schools - Teachers									
#1 Preschool	3	3.3E-07	NA[b]	6.1E-10	NA	3.3E-07	4.9E-05	4.9E-05	Adult
#2 Jr. High	3	3.3E-07	NA	6.1E-10	NA	3.3E-07	1.8E-05	1.9E-05	Adult
#3 High School[f]	35	3.8E-06	NA	7.1E-09	NA	3.8E-06	6.7E-05	7.1E-05	Adult
3-A	34	3.7E-06	NA	6.9E-09	NA	3.7E-06	6.7E-05	7.1E-05	Adult
3-B	34	3.7E-06	NA	6.9E-09	NA	3.7E-06	2.4E-05	2.8E-05	Adult
3-C/D	35	3.8E-06	NA	7.1E-09	NA	3.8E-06	6.1E-05	6.5E-05	Adult
Residences									
4[f]	780	2.5E-04	1.7E-04	4.3E-08	7.8E0-4	1.2E-03	1.9E-03	3.1E-03	Adult/Child
4-A	780	2.5E-04	1.7E-04	4.3E-08	NA	4.1E-04	1.9E-03	2.3E-03	Adult/Child
4-B	780	2.5E-04	8.3E-05	4.3E-08	7.8E-04	1.1E-03	1.9E-03	3.0E-03	Adult/Child

Table 2-5. Health Risks of Present Land Uses, West Chicago Off-site Properties

Location	Th-232[a] (pCi/g)	Soil Ingestion Risk	Ingestion Veg. & Fruit Risk	Inhalation of Particulates Risk	Inhalation of Th/Rn Risk	Total Inhalation & Ingestion Risk	Gamma Exposure Risk	Total Risk	Exposed Person
5	490	1.5E-4	5.2E-04	4.3E-08	NA	6.7E-04	8.5E-05	7.6E-04	Adult/Child
6	200	6.3E-5	2.1E-05	1.7E-08	NA	8.4E-05	1.7E-04	2.5E-04	Adult/Child
7	28	8.8E-6	3.0E-05	3.1E-09	NA	3.9E-05	3.0E-04	3.4E-04	Adult/Child

(a) All progeny of Th-232 and U-238 are assumed to be in secular equilibrium with the head of their respective chains. U-238 concentrations are 10 percent of those for Th-232.

(b) Estimated net soil concentration, based on measured net gamma exposure rate. A soil sample was not taken.

(c) Total (gross) measured soil concentration. Since measurements of the natural background concentration were not obtained, this was selected as a prudently conservative value for these assessments.

(d) This and subsequent values are basically total or gross concentrations (background not subtracted). However, natural background would not contribute significantly to these values.

(e) NA: Not applicable.

(f) Assumes maximum value for each pathway.

schools range from 1.9E-5 to 7.1E-5. The risks at the subject residences range from 2.5E-4 to 3.1E-3. It is possible that a single individual could be exposed at two or more of these locations, and that these risks would be additive. For example, if an individual were to attend all three schools and live in the residence for which that highest risk is calculated, then his or her total risk would be about 3.1E-3 or approximately 3 per thousand over a 30 year period.

The risk from present use conditions at all of the schools and at one of the residential properties is primarily due to external gamma exposure during activities outside of the schools and residences. The exposure times postulated for these sites vary from 0.5 to 3 hours per day (see Tables 2-1 and 2-4). The exposure rates indicated for the properties (see Table 2-2) do not always correspond directly with the measured concentrations for the contaminants in soil. This is generally due to significant areas of the contaminants being covered with asphalt or uncontaminated soil (e.g. School #3 and Residences #5 and #6). To provide upper-bound risk estimates, it has been assumed that sufficient soil was available for the ingestion scenarios to be applicable, even though areas of the contamination may be covered. The present use gamma estimates are based on the present gamma exposure rates. However, it should be recognized that if the cover material were removed, the direct radiation risks would increase.

Pathways other than external gamma are major contributors to risk at several of the residential locations because of the reduction of the external gamma by "over-burden" material. For example, for Residence No. 4, the risk from the external gamma exposure would be over 5E-3 if the gamma dose was directly related to the measurement of the Th-232 in soil (i.e., 780 pCi/g) However, the risk calculated based on the gamma dose measured in the presence of the over-burden material is 1.9E-3. Similar circumstances exist at the other sites, where the measured gamma exposure rate, and the associated risk, is only a fraction of the gamma exposure rate that would exist if the full area of contamination contained material with the measured concentration and there was no over-burden material.

Inclusion of the child soil ingestion scenario also increases the significance of the risks from pathways other than external gamma exposure. For example, for Residence No. 5, 20 percent of the risk, 1.5E-4, is from the soil ingestion pathway. This total results from adding the projected risk for a child from age 0 to 6 for ingestion of soil, 5.2E-5, to the risk of 1.0E-4 for the adult ingestion of soil over a 24 year period. Thus, 34 percent of the soil ingestion risk is from ingestion of soil by the child. For comparison, the risk for an adult ingesting soil for 30 years is 1.3E-4. Thus, making allowances for childhood increases the risk estimate by 15 percent.

2.2.2 Future Land Uses, With No Remediation

The potential radiation health risks for future land uses, without remediation, are given in Table 2-6. This future land use scenario is based on a residence being built directly over the area of maximum contamination at each location. Any existing over-burden material (e.g., asphalt, etc.) is assumed to be removed from the area where the residence is built. The risks vary from about 7.0E-4 (70 per 100,000) to as high as 8.6E-2, or about 9 in 100. The total risks for these scenarios are generally proportional to the concentrations of Th-232 at the properties, subject to modifications due to the area of contamination.

All these risks are based on 30 years of exposure, including 6 years of exposure as a child. It is assumed that the maximum exposed individual is present in the house 75 percent of the time. The 75 percent occupancy value is taken from the EPA scenario for indoor radon (EPA89c).

These are not maximized risks because the over-burden material, which reduces the outside external gamma exposure, is assumed to remain in place. However, the risk from the external gamma dose received during exterior activities is a small enough fraction of the total that, even if the overburden was assumed to be removed, the total risk would not be greatly increased.

The risks in Table 2-6 for unrestricted future land use apply the same scenario for all of the locations. The most significant sources of the risk are the gamma exposure (indoor plus outdoor) and indoor radon/thoron exposures. The risks for these pathways and for inhalation and the contamination size modifying factors are given in Appendix B.

Table 2-6. Health Risks for Unrestricted Future Land Uses, West Chicago Off-site Properties[a]

Location		Th-232[b] (pCi/g)	Soil Ingestion Risk	Ingestion Veg. & Fruit Risk	Inhalation of Particulates Risk	Inhalation of Th/Rn Risk	Total Inhalation & Ingestion Risk	Gamma Exposure Risk	Total Risk
Schools									
#1	Preschool	3	9.5E-07	3.2E-06	3.3E-10	3.0E-05	3.4E-05	6.9E-04	7.2E-04
#2	Jr. High	3	9.5E-07	3.2E-06	3.3E-10	3.0E-05	3.4E-05	6.7E-04	7.0E-04
#3	High School[c]	35	1.1E-05	3.7E-05	3.8E-09	3.5E-05	4.0E-04	7.7E-03	8.1E-03
	3-A	34	1.1E-05	3.6E-05	3.7E-09	3.4E-04	3.9E-04	7.5E-03	7.9E-03
	3-B	34	1.1E-05	3.6E-05	3.7E-09	3.4E-04	3.9E-04	7.7E-03	8.1E-03
	3-C/D	35	1.1E-05	3.7E-05	3.8E-09	3.5E-04	4.0E-04	6.7E-03	7.1E-03
Residences									
4[c]		780	2.5E-04	8.3E-04	4.3E-08	7.8E-03	8.9E-03	7.7E-02	8.6E-02
	4-A	780	2.5E-04	8.3E-04	4.3E-08	7.8E-03	8.9E-03	7.7E-02	8.6E-02
	4-B	780	2.5E-04	8.3E-04	4.3E-08	7.8E-03	8.9E-03	7.7E-02	8.6E-02
5		490	1.5E-04	4.2E-04	4.3E-08	4.9E-03	5.5E-03	5.5E-02	6.0E-02
6		200	6.3E-05	2.1E-04	1.7E-08	2.0E-03	2.3E-03	1.9E-02	2.1E-02
7		28	8.8E-06	3.0E-05	3.1E-09	2.8E-04	3.2E-04	5.6E-03	5.9E-03

(a) All future health risks represent a combination of 6 years of exposure as a child and 24 years of exposure as an adult.
(b) All progeny of Th-232 and U-238 are assumed to be in secular equalibrium with the head of their respective chains. U-238 concentrations are 10 percent of those for Th-232.
(c) Assumes maximum value for each pathway.

2.3 SUMMARY

Ore residuals containing radioactive contamination were distributed in the West Chicago, Illinois, area during the early years of the operation of the West Chicago Rare Earths Facility. Many of the sites have been remediated. However, there are still residential and school sites, and possibly other sites, with residual contamination.

The contamination is primarily comprised of Th-232 and its progeny. However, there is also residual radioactivity associated with the U-238 decay chain, including Ra-226. These off-site properties have been listed on the National Priorities List (NPL) by the U.S. Environmental Protection Agency (EPA). This report provides focused risk assessments for three (3) schools and four (4) residential properties identified by EPA. Risk evaluations are provided for present and future land use conditions. No significant amount of contamination has been found under the designated homes or schools. Therefore, the present land use risks are primarily limited to scenarios for exposures outside of structures. For future land use scenarios, it is assumed that homes are built over the contaminated areas, and indoor exposure scenarios are used.

The risk assessments are based on school attendance durations of 2 to 4 years for children, 25 years for teachers and a 30-year occupancy time for residences. The residence time of 30 years is the upper bound of normal residence in a home (EPA91). The exposure scenarios apply applicable exposure parameters from EPA guidance documents (EP89a, EPA89b, and EPA91). The EPA risk parameters or slope factors from the HEAST tables (EPA92) are generally used to determine the health risks for total cancers (mortality plus morbidity).

The present use risks for the schools are an average of about 2E-5 for students and 5E-5 for teachers based on contamination levels of 3 to 35 pCi/g of Th-232. The risks for future unrestricted land use at these locations is about 7E-3.

The health risk assessments for the four residences indicate that the average present land use risks are about 1 per 1,000 or 1E-3. The risks for future unrestricted land uses are projected to be much higher because it is assumed that residences are built over existing contamination. These risks for future conditions at the specified residences range from about 6 per 1,000 (6E-3) to up to 9 per 100 (9E-2).

2.4 UNCERTAINTY OF RISK ASSESSMENTS

There are several basic sources of uncertainty in the health risk assessments. These uncertainties can be categorized as follows:

- Characterization of the contamination on the sites.
- Applicability of assumptions for the pathways risk assessments to people actually present on the sites, and the applicability of pathways models and parameters to the specific sites and circumstances.
- Risk assessment parameters.

These categories of uncertainties are addressed in the following sections. These discussions of uncertainties only consider the broad scope of unknowns. A more extensive analysis is beyond the scope of this document.

2.4.1 Characterization of Contamination on the Sites

The site characterizations are based on limited surveys with radiation survey meters and, in most cases, analysis of a single sample of soil. The data base used for the assessments in this report generally only contains maximum radiation survey measurements, an indication of the general area where contamination was found, and the results of a soil sample from the area where the highest radiation measurement was found. Over-burden soil and asphalt over the contamination attenuates the radiation emitted from the contaminants making it hard to identify the actual area of contamination and difficult to know where to sample to obtain an applicable example of the contamination. Also, only limited analyses were performed on the samples. The samples were generally analyzed by gamma spectroscopy. Results were only given for the radionuclides related to Ra-226 and Ra-228, radium isotopes from the U-238 and Th-232 decay chains. It is known that uranium and thorium were removed during the processing of ores at the Rare Earths Facility (EPA86), but since detailed analysis was not provided for the site survey samples, it was assumed all the radionuclides in the U-238 and Th-232 decay chains were present in secular equilibrium.

Adjustment factors were used to reduce the projected risks to account for site specific conditions. The estimated sizes of the areas of contamination are given in Table 2-2. The adjustment factors are given in Table B-6 in Appendix B. The site characterizations were based on limited radiation surveys. Boreholes were not used to define the areas and depths of contamination. Experience with remedial actions indicates that the areas and depths of contamination are often greater than what is projected from surveys. The focus of these risk assessments was to provide upper bound estimates of the risks, and when there were uncertainties, to error on the conservative side. However, an effort was also made to provide reasonable estimates. The adjustment factors were used to reduce projected risks based on the presence of limited areas of contamination and/or isolation of the contamination by overburden. For example, the assumptions for the resuspension of activity to produce an airborne source term for inhalation require a relatively large area of contamination to be exposed at the surface. If this was not the case, the estimate was reduced using the factors in Table B-6.

The external gamma risks for exposure outside of structures are based on actual net measurements (gross minus natural background) of the gamma exposure rates. However, only the maximum measurements were reported for most properties. A general rule of thumb is that the maximum environmental measurements are generally a factor of about three above the average values.

The external gamma risks for exposure inside structures, based on future unrestricted use of the properties, are based on gamma exposures calculated from the soil concentrations. Shielding by the structures is included. The estimates are based on finite source estimates of a contaminated area about the size of a house and one or two feet thick, based on the information in Table 2-2. An adjustment factor was also used (Table B-6) for sites with a relatively small area of contamination.

The site surveys were generally based on obtaining a soil sample from the area of maximum contamination. However, soil samples are generally taken from a small area of a square foot or a fraction of a square foot and generally from a discrete depth of about 6 inches to 12 inches. The reality is, it is difficult to characterize contamination with a single sample.

In order to provide reasonable confidence of performing an upper bound assessment, it is necessary to use the direct results from the site screening, even though the screening objective was to identify the maximum levels of contamination. Based on technical experience, maximum results are nominally three times representative averages; therefore it is estimated that use of the maximum results from the site screening work may result in up to a factor of three (3) conservatism.

The contamination on several of the properties is covered by overburden soil and/or asphalt. The shielding by the overburden results in the external gamma exposure rate, generally the limiting risk pathway, being reduced by a factor of more than ten (10). The actual observed gamma exposure rates, versus the exposure rates based on the measured soil concentrations, are used for assessing the risk for external gamma exposure outside. The approach provides the more reasonable assessment of present land use health risks. However, even for present land uses, the overburden material could be removed and the gamma exposure rate and associated health risk would be higher by a factor of ten (10) or more for several of the properties. This is one of the few uncertainties that would result in an increase in the risks.

In summary, it is believed that the interpretation and use of the site survey data generally results in conservative assessments. It is projected that the estimated risks are probably a factor of two to three greater than reflected by actual contamination at the sites. However, it is also apparent that relatively minor modifications at the sites could result in increases in the risks by a factor of about 10 or more due to the removal of the overburden which is providing some shielding.

2.4.2 Assumptions for Pathways Assessments and Parameters

The people present at the sites and the characteristics of the people have not been identified. In order to provide upper-bound risk estimates, the effort has been to develop conservative scenarios to represent the people present at the sites. Given the lack of identification of the specific people that are present, it is likely that the actual risks have been over estimated by selection of conservative characteristics. For example, a child of 0 to 6 years old is included for the scenarios at all of the residences. Based on the conservative parameters used for the soil ingestion pathway, the risk to the child is for several cases the most significant risk for the 30-year resident scenario. If a child is not or has not been present from birth till age 6 years, this scenario is not pertinent for the present land use assessment.

Other conservative assumptions include the incorporation of food pathways. The food pathways assume that food crops grown in the contamination represent a significant fraction of the normal diet of vegetables and fruit for individuals living on the site. This assumption was used even though EPA personnel report that very little fruit is grown in the area, and gardening may be limited to relatively small gardens.

The following items identify assumptions that are relatively significant in determining the projected health risks, but where there is considerable uncertainty:

- It is assumed that children between the ages of 0 to 6 years old ingest 0.2 grams of soil per day. It is also assumed that an adult ingests 0.05 gram of soil per day at work and 0.2 gram of soil per day at home. Given that much of the contaminated material is isolated by overburden, the probability of continuous ingestion of these quantities of contaminated soil is small.

- The likelihood of growing food products in the areas of maximum contamination and ingesting significant quantities of the food products is small.

- The chance of children or adults spending the specified occupancy times outside in the areas of maximum contamination (e.g., 0.5 hours per day at residences and 2 to 3 hours per day at school) is small.

- The indoor scenarios for future unrestricted use of the sites is based on 75 percent occupancy for 350 days (50 weeks) of the year. It is conservative to assume continuous occupancy would occur for the 30 year period of exposure.

2.4.3 Uncertainty of Risk Parameters

The health risk parameters from the EPA HEAST tables (EPA92) were used for the inhalation and ingestion pathways and risk parameters from the EPA assessment for the Clean Air Act background documents of 1989 (EPA89) were used for assessing the external gamma exposures. These risk parameters are based on health effects that have been observed at radiation doses up to several orders of magnitude above the doses related to these sites. There is considerable uncertainty in extrapolating the observed health effects to the low dose levels associated with these activities. While there is some consideration that actual health effects may be higher than those projected with the subject risk factors, it is possible that actual health effects will be less (EPA89c).

2.4.4 Summary of Uncertainties

The selection of site characterization data, exposure scenarios and associated parameters, and risk parameters has focused on providing upper bound risk estimates. While it is possible and even probable that some assumptions have resulted in underestimating the health risks for the contamination at these sites, it is more likely that the reported health risks are conservative. It is difficult to assess the degree of conservatism, but a general compilation of the uncertainty factors implies that the reported health risks are conservative by at least a factor of three to a factor of ten or more. The site characterization data is about the only area of uncertainty that is considered to have possibly resulted in an underestimate of the health effects risks. However, the effort was also made to use upper bound (conservative) site characterization information.

2.5 REFERENCES

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3. Part II: Assessment of Doses and Risks Associated with a New Storage Pile

3.1 INTRODUCTION

This section presents the calculated doses and risks that would result if contaminated soil removed by anticipated remediation activities was stored at the Rare Earths Facility (REF) site. External exposure rates, doses, and total cancer risk as a function of distance from a pile of this contaminated soil are presented in this section. These analyses are limited to direct gamma radiation since the waste pile is assumed to be covered, thereby eliminating radon and thoron emanation and the suspension of particulates. Inadvertent intrusion scenarios are not addressed since it is assumed that the storage area would be under continual institutional control. The contribution to dose and risk from existing tailings piles and other contaminated materials stored at the facility are also discussed.

The storage pile is assumed to be a 6404 cubic meter (226,130 cubic foot) hemisphere containing an average radionuclide concentration of 3.24 pCi/g of U-238 and 32.44 pCi/g of Th-232 in equilibrium with their progeny. The volume of soil and its average radionuclide concentration are based on information provided in Table 2-2 of Section 2.

Values are presented for exposure rates and annual indoor and outdoor doses. Health risks are presented for exposure periods of one and 30 years.

3.2 METHODOLOGY

3.2.1 Exposures

Exposure rates are calculated using both the QAD-CGGP (RSIC88) and Microshield (GE88) computer codes. QAD-CGGP, which allows the user to calculate the exposure rate anywhere the user wishes, was used to calculate exposures at locations 1 to 30 feet from the pile assuming that the exposure points are 1 meter (3.3 feet) above the ground. For distances greater than 30 feet, there is very little difference between the exposure calculated for a point directly opposite the equator of the sphere and a point 1 meter (3.3 feet) above a plane through the equator. Therefore Microshield, which runs faster than QAD-CGGP, was used to calculated all exposures greater than 30 feet.

QAD-CGGP is a point-kernel integration code for calculating gamma ray fluxes and dose rates at specific exposure locations within a three-dimensional shielding geometry configuration due to radiation from a volume-distributed source. The program calculates gamma-ray fluxes and dose rates at discrete locations within a complex source-geometry configuration by representing a volume-distributed source by a number of point isotropic sources and computing the distances through all regions traversed by the line-of-sight from the source points to a desired receiver point. From these distances and the characteristics of the materials within them, energy dependent exponential attenuation factors and energy-dependent buildup factors for gamma rays are applied to calculate the direct gamma-ray dose and the direct gamma ray-dose with buildup. The QAD-CGGP buildup factor calculations use the Geometric Progression (GP) fitting function parameters determined by Y. Harima, Tokyo Institute of Technology, and Y. Sakamoto, Japan Atomic Energy Research Institute, from buildup factor data compiled by American Nuclear Society Working Group ANS-6.4.3. This capability was incorporated into the program in 1988.

Microshield is a PC version of ISOSHLD, a computer program that performs gamma-ray shielding calculations for radioactive sources for a wide variety of source and shield configurations. Attenuation calculations are performed by point kernel integration; i.e., the dose at the exposure point is the contribution from a large number of point sources. A numerical integration is carried out over the source volume to obtain the total dose. Buildup factors are used and are calculated by the code based on the number of mean free paths of material between the source and exposure point locations, the effective atomic number of a particular shield region, and the point isotropic buildup data available as Taylor coefficients in the effective atomic number range of 4 to 92 (NDA54). For most problems, the user need only supply (1) the geometry and material composition of the source and of the shields and (2) the thicknesses and distances involved. The choices of geometries are:

- Point with slab shields
- Line with slab shields
- Sphere with spherical shields
- Sphere with slab shields
- Truncated cone with slab shields
- Disk with slab shields

- Cylinder from side with cylindrical shields
- Cylinder from side with slab shields
- Cylinder from side with cylindrical and slab shields
- Cylinder from end with slab shields
- Rectangular solid with slab shields
- Rectangular area with slab shields
- Infinite plane with slab shields
- Infinite slab with slab shields

The dirt pile is hemispherical; however, Microshield can only model a sphere. Symmetry was used to overcome this problem. The hemispherical dirt pile was modeled using the sphere with spherical shields geometry. The sphere is assumed to contain twice the volume of the actual hemisphere and half the source strength. A receptor opposite the equator of this sphere sees the same exposure as from the original hemisphere.

Either activities or concentrations can be entered. The user can choose to decay the original activity before calculating exposures. Shield materials can be chosen from a list of built in materials or the user can create a customized material.

QAD-CGGP requires the user to input the source strength, the average gamma energy, and the exposure conversion factor for that energy. Microshield has a built in library of nuclide data. When a user enters the source activity by selecting radionuclides, the program retrieves the photon activity from this library. Individual gammas from each specific isotope are sorted into energy groups (see Section 7.2 of Ge88 for the methodology). As part of its output, the program prints the total number of photons emitted per second from the radionuclide selected by energy group. The Microshield output also includes the energy flux (MeV/cm^2/sec) and the exposure rate (mR/hr) by energy group. This information was used to derive the exposure conversion factors which were input to the QAD-CGGP program so that both codes were using the same factors.

As stated before, Microshield can only do the calculation for a sphere. Therefore, the program was run for a sphere containing twice the volume of the actual hemisphere and half the source strength. Based on the above assumption that the hemisphere contains 6404 cubic meters (226,130 cubic feet), a sphere with a radius of 1,451.4 centimeters (47.62 feet) was used in the calculations.

The concentration for Microshield is input in terms of μCi/cc. A soil density of 1.6 g/cc is assumed. Thus the concentration for U-238 and its progeny is:

$$((3.24\ pCi/g)\ (\mu Ci/1E+6\ pCi)\ (1.6\ g/cc))/2 = 2.E\text{-}6\ \mu Ci/cc.$$

For Th-232 plus progeny, the concentration used is:

$$((32.44\ pCi/g)\ (\mu Ci/1E+6\ pCi)\ (1.6\ g/cc))/2 = 2.595E\text{-}5\ \mu Ci/cc.$$

The energy groups, source strengths, and exposure conversion factors derived from the Microshield program for use in QAD-CGGP are presented in Table 3-1. No decay correction is applied due to the long half-lives of both chain parents.

Symmetry was also used when setting up the QAD-CGGP runs. In order to reduce the run time of the program, the total source was assumed to be distributed evenly throughout a quarter of a sphere. Exposure points are placed so that the exposure calculated by integrating over the quarter of a sphere having the full source strength is equal to that which would be calculated by integrating over the full hemisphere with the same total source strength. In other words, the concentration in the quarter sphere is double that in the full hemisphere.

Both programs use the same soil composition. This composition is taken from a study by H. Beck and G. de Planque entitled "The Radiation Field in Air Due to Distributed Gamma-Ray Sources in the Ground" (AEC68). The composition consists of 67.5 percent SiO_2, 13.5 percent Al_3O_3, 4.5 percent Fe_2O_3, 4.5 percent CO_2, and 10 percent H_2O. Table 3-2 presents the breakdown by element. The soil density assumed is 1.6 g/cc in both programs.

The Geometric Progression fitting function parameters for water were used to calculate the buildup factor when running QAD-CGGP. Microshield interpolates between the Taylor coefficients for beryllium (atomic number 4) and aluminum (atomic number 11) based on an effective atomic number of 8 that it calculates for the soil mixture. Despite these differences, the buildup factor values calculated by both programs agree within 4 percent, and the total exposure calculated at 10 meters (33 feet) from the equator of the sphere only differs by 2 percent. Therefore, this difference in calculational methods is not significant.

Table 3-1. Energy groups, source strengths, and exposure conversion factors as calculated by Microshield for uranium-238 and thorium-232 in equilibrium with their progeny.

Parent Nuclide	Group	MeV	gammas/sec	mR/hr per $MeV/cm^2/sec$
Uranium-238[1]	1	2.1424	1.342E+8	0.00159
	2	1.6272	4.087E+8	0.00173
	3	1.1562	3.661E+8	0.00187
	4	0.8284	1.628E+8	0.00200
	5	0.6041	6.004E+8	0.00207
	6	0.4677	2.300E+7	0.00204
	7	0.3522	4.667E+8	0.00206
	8	0.2755	3.454E+8	0.00199
	9	0.1794	4.114E+7	0.00180
	10	0.1172	4.535E+6	0.00158
Thorium-232[2]	1	1.5858	1.673E+9	0.00174
	2	1.1390	2.937E+8	0.00187
	3	0.9188	8.211E+9	0.00196
	4	0.7307	1.944E+9	0.00204
	5	0.4855	9.271E+8	0.00204
	6	0.3478	1.776E+9	0.00206
	7	0.2985	1.369E+9	0.00201
	8	0.2389	6.653E+9	0.00193
	9	0.1523	1.674E+8	0.00174
	10	0.1211	6.283E+8	0.00160

1 U-238 progeny included are Th-234, Pa-234m, U-234, Th-230, Ra-226, Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, and Po-210.

2 Th-232 progeny included are Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, and Bi-212.

Annual exposures are calculated for a resident assuming that the person is home 75 percent of the day for 350 days each year and that 0.5 hours per day are spent in outdoor activities. It is further assumed that exposure received while in the home is less than that received outdoors by a factor of 0.8 (Oa72).

Table 3-2. Air and Soil Partial Densities[1] Used in QAD-CGGP

Element	Air (g/cc)	Soil (g/cc)
Hydrogen	0.	0.0179
Carbon	0.	0.0195
Nitrogen	0.001010	0.
Oxygen	0.000271	0.8935
Aluminum	0.	0.1144
Silicon	0.	0.5043
Argon	0.000012	0.
Fe	0.	0.0503
Total	0.001293	1.5999

1. Partial density is that portion of the total material density that is attributable to the individual element, i.e., the sum of the partial densities equals the total density.

3.2.2 Risks

Annual and lifetime health risks are calculated using 6.23E-4 total cancers per rad (EPA89b). Approximately 60 percent of these cancers are fatal (EPA89b). It is assumed that one roentgen equals one rad equals one rem for the purpose of this study. Lifetime risks for a resident are calculated assuming 30 years of exposure. The period of residency is taken as 30 years since this is the maximum period of time generally spent at one residence in the U.S (EPA91a).

3.3 RESULTS

3.3.1 On-site and REF Property Fence Line Doses and Risks

Table 3-3 presents the exposure rate as a function of distance from the surface of the contaminated dirt pile. A person standing at a distance of 1 ft from the storage pile

Table 3-3. Annual External Exposure and Dose as a Function of Distance from a 226,130 ft^3 Hemisphere of Contaminated Soil[a]

Distance (feet)	U-238 + Progeny[b] (μR/hr)	Th-232 + Progeny[c] (μR/hr)	Total (μR/hr)	Annual Outdoor Dose[d]: U-238 + Progeny (mrem/yr)	Annual Outdoor Dose[d]: Th-232 + Progeny (mrem/yr)	Annual Outdoor Dose[d]: Total (mR/hr)	Annual Indoor Dose[d]: U-238 + Progeny (mrem/yr)	Annual Indoor Dose[d]: Th-232 + Progeny (mrem/yr)	Annual Indoor Dose[d]: Total (mrem/yr)	Total Annual Dose[d]: U-238 + Progeny (mrem/yr)	Total Annual Dose[d]: Th-232 + Progeny (mrem/yr)	Total Annual Dose[d]: Total (mrem/yr)
1	4.0E+00	2.8E+01	3.2E+01	7.0E-01	4.9E+00	5.6E+00	2.0E+01	1.4E+02	1.6E+02	2.1E+01	1.5E+02	1.7E+02
5	3.0E+00	2.1E+01	2.4E+01	5.2E-01	3.7E+00	4.2E+00	1.5E+01	1.1E+02	1.2E+02	1.6E+01	1.1E+02	1.3E+02
10	2.0E+00	1.4E+01	1.6E+01	3.4E-01	2.4E+00	2.8E+00	9.9E+00	7.0E+01	8.0E+01	1.0E+01	7.2E+01	8.3E+01
15	1.5E+00	1.0E+01	1.2E+01	2.6E-01	1.8E+00	2.1E+00	7.4E+00	5.2E+01	6.0E+01	7.7E+00	5.4E+01	6.2E+01
20	1.2E+00	8.2E+00	9.4E+00	2.0E-01	1.4E+00	1.6E+00	5.9E+00	4.1E+01	4.7E+01	6.1E+00	4.3E+01	4.9E+01
25	9.5E-01	6.7E+00	7.7E+00	1.7E-01	1.2E+00	1.3E+00	4.8E+00	3.4E+01	3.9E+01	5.0E+00	3.5E+01	4.0E+01
30	8.0E-01	5.6E+00	6.4E+00	1.4E-01	9.8E-01	1.1E+00	4.0E+00	2.8E+01	3.2E+01	4.2E+00	2.9E+01	3.4E+01
35	6.9E-01	4.8E+00	5.4E+00	1.2E-01	8.3E-01	9.5E-01	3.5E+00	2.4E+01	2.7E+01	3.6E+00	2.5E+01	2.8E+01
40	6.0E-01	4.2E+00	4.8E+00	1.1E-01	7.3E-01	8.3E-01	3.0E+00	2.1E+01	2.4E+01	3.2E+00	2.2E+01	2.5E+01
45	5.3E-01	3.7E+00	4.2E+00	9.3E-02	6.4E-01	7.3E-01	2.7E+00	1.8E+01	2.1E+01	2.8E+00	1.9E+01	2.2E+01
50	4.7E-01	3.2E+00	3.7E+00	8.3E-02	5.7E-01	6.5E-01	2.4E+00	1.6E+01	1.9E+01	2.5E+00	1.7E+01	1.9E+01
100	1.9E-01	1.3E+00	1.5E+00	3.3E-02	2.2E-01	2.6E-01	9.5E-01	6.5E+00	7.4E+00	9.8E-01	6.7E+00	7.7E+00
200	5.8E-02	3.9E-01	4.5E-01	1.0E-02	6.9E-02	7.9E-02	2.9E-01	2.0E+00	2.3E+00	3.0E-01	2.0E+00	2.4E+00
300	2.6E-02	1.7E-01	2.0E-01	4.5E-03	3.0E-02	3.5E-02	1.3E-01	8.7E-01	1.0E+00	1.3E-01	9.0E-01	1.0E+00
400	1.4E-02	8.9E-02	1.0E-01	2.4E-03	1.6E-02	1.8E-02	6.8E-02	4.5E-01	5.2E-01	7.1E-02	4.6E-01	5.3E-01
500	7.8E-03	5.0E-02	5.8E-02	1.4E-03	8.8E-03	1.0E-02	3.9E-02	2.5E-01	2.9E-01	4.1E-02	2.6E-01	3.0E-01
600	4.8E-03	3.1E-02	3.5E-02	8.5E-04	5.3E-03	6.2E-03	2.4E-02	1.5E-01	1.8E-01	2.5E-02	1.6E-01	1.8E-01
700	3.1E-03	1.9E-02	2.2E-02	5.5E-04	3.4E-03	3.9E-03	1.6E-02	9.7E-02	1.1E-01	1.6E-02	1.0E-01	1.2E-01
800	2.1E-03	1.3E-02	1.5E-02	3.6E-04	2.2E-03	2.6E-03	1.0E-02	6.4E-02	7.4E-02	1.1E-02	6.6E-02	7.7E-02
900	1.4E-03	8.5E-03	9.9E-03	2.5E-04	1.5E-03	1.7E-03	7.2E-03	4.3E-02	5.0E-02	7.4E-03	4.4E-02	5.2E-02
1000	1.0E-03	5.8E-03	6.8E-03	1.7E-04	1.0E-03	1.2E-03	5.0E-03	2.9E-02	3.4E-02	5.2E-03	3.0E-02	3.6E-02
1100	7.1E-04	4.1E-03	4.8E-03	1.2E-04	7.1E-04	8.3E-04	3.6E-03	2.0E-02	2.4E-02	3.7E-03	2.1E-02	2.5E-02
1200	5.1E-04	2.9E-03	3.4E-03	9.0E-05	5.0E-04	5.9E-04	2.6E-03	1.4E-02	1.7E-02	2.7E-03	1.5E-02	1.8E-02

a. All doses are above background at one meter above the ground surface. The annual doses assume 75% of the time is spent at home. Of this, 6,300 hours are spent indoors and 175 hours outdoors.
b. U-238 concentration in soil is assumed to be 3.24 pCi/g in equilibrium with its progeny.
c. Th-232 concentration in soil is assumed to be 32.44 pCi/g in equilibrium with its progeny.
d. Assumes 1 R = 1 rad = 1 rem. Dose in this case means dose equivalent.

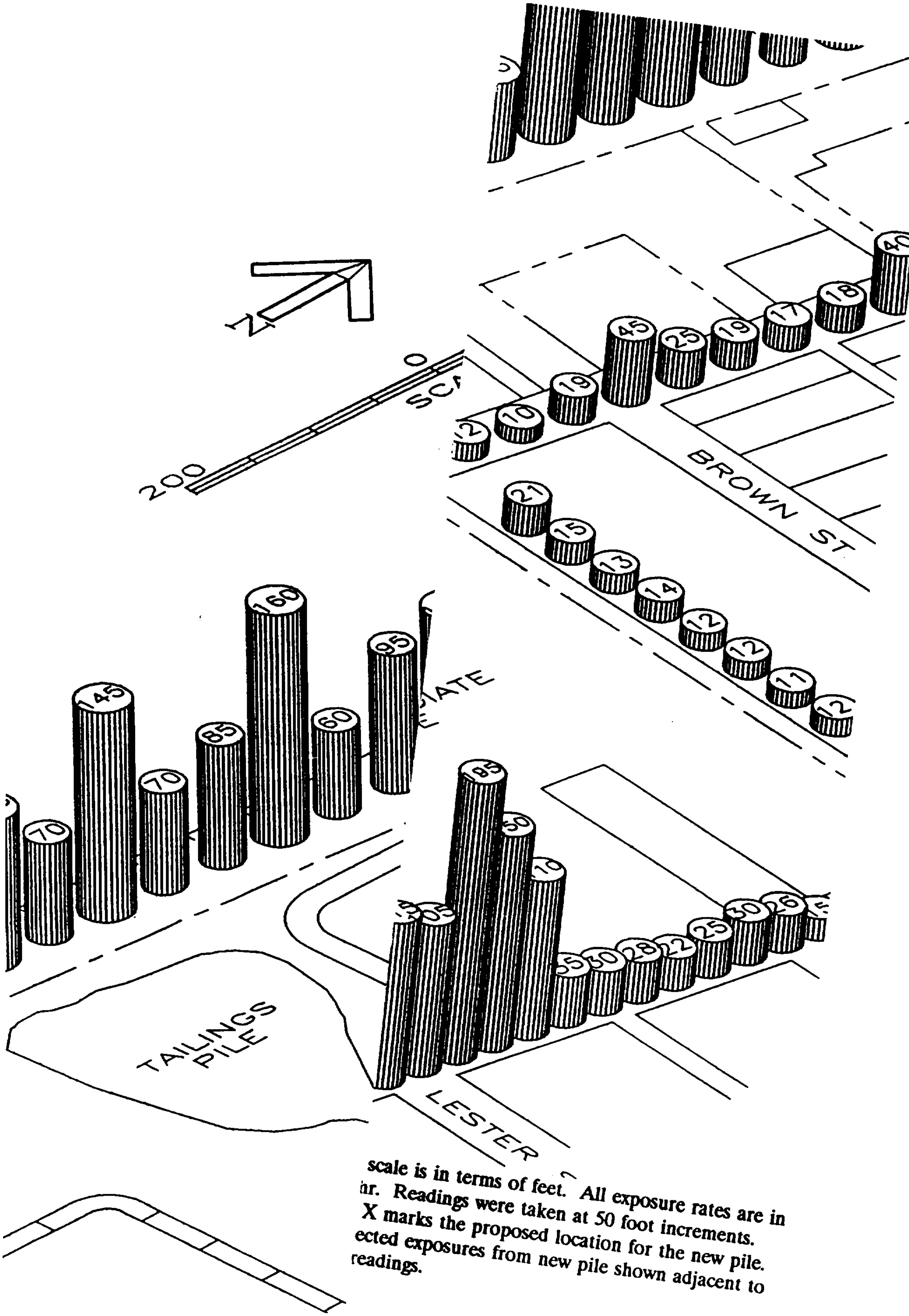
would be exposed at a rate of about 32 μR/hr above background. This is about five times the exposure rate from natural external background radiation (approximately 7 μR/hr). For each hour at the site in close proximity to the storage pile, the person's potential lifetime risk of cancer due to this exposure is about 2E-8.

As can be seen from Table 3-3, the exposure rate from the contaminated dirt drops to approximately 7 μR/hr, a rate comparable to normal background, at about 28 feet from the pile. When total radiation levels are less than twice background, it becomes difficult to detect elevated radiation levels using conventional survey meters. Thus, at approximately 28 feet from the pile, it would be difficult to discern the elevated exposure resulting from the pile.

In reality, background levels at the facility in the area where the pile is to be placed are greater than normal due to the presence of old tailings piles and other contamination from past activities. Figure 3-1 presents the gross exposures rates (net plus background) measured at the fence along the property boundary near where the new pile would be placed. The location being considered for the new pile is indicated with an X. The center of the new pile is approximately 100 feet, and the surface is about 50 feet, from the closest REF property fence line. That closest property line is the west fence which boarders the Elgin, Joliet, and Eastern Railroad tracks.

Inspection of Table 3-3 reveals that at a distance of 50 to 100 feet from the surface of the new pile the exposure rate due to the new pile is about 1 to 4 μR/hr. Accordingly, at the closest fence line (west of the new pile), the new pile will add a few μR/hr to a preexisting exposure rate ranging from 39 to 110 μR/hr. This is equivalent to a 5 percent to 10 percent increase in the exposure rate, which would be marginally discernable using conventional survey meters. The total health risk associated with an exposure rate of 4 μR/hr is an incremental increase in the lifetime risk of cancer of 2.5E-9 for every hour of exposure.

Figure 3-1 also illustrates how the fence line gross exposure rates would increase along the property fence line if the pile of contaminated dirt were placed in the proposed location. At all locations, the incremental increase in exposure rate due to the new pile will not be discernable at the REF property boundary.



scale is in terms of feet. All exposure rates are in
hr. Readings were taken at 50 foot increments.
X marks the proposed location for the new pile.
ected exposures from new pile shown adjacent to
readings.

Figure 3-1. Gross Measured an
Rare Earths Facilit

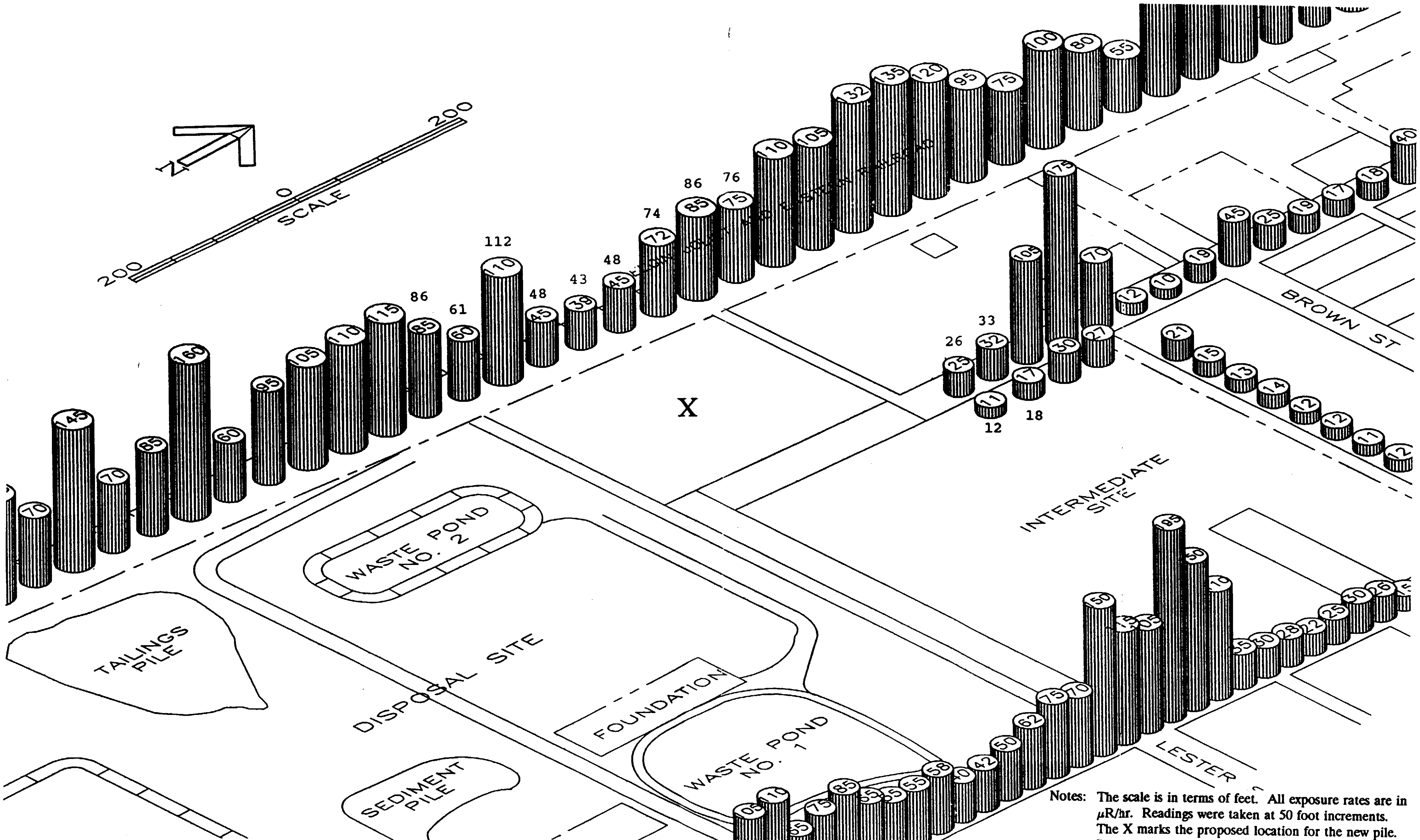


Figure 3-1. Gross Measured and Projected Gamma Exposures at the West Chicago Rare Earths Facility

Notes: The scale is in terms of feet. All exposure rates are in μR/hr. Readings were taken at 50 foot increments. The X marks the proposed location for the new pile. Projected exposures from new pile shown adjacent to old readings.

3.3.2 Dose and Risk to a Resident

Table 3-3 and Figures 3-2 through 3-5 present the exposure rate and annual dose equivalent for a resident as a function of distance from the contaminated dirt pile. Table 3-4 and Figures 3-6 and 3-7 present total cancer risk for a resident due to the additional exposure as a function of distance from the storage pile.

The distance from the edge of the proposed storage pile to the nearest resident is approximately 400 feet. At that distance, the unshielded exposure rate from the new pile would be 0.1 μR/hr, a rate which would not be discernable from background. Assuming that the resident is home for 75 percent of the day for 350 days each year, that 0.5 hours a day are spent outside the residence, and that exposures inside the residence are less than those received outside by a factor of 0.8, the annual dose to the resident would be 0.53 mrem. At an annual dose rate of 0.53 mrem/yr for 30 years, the incremental increase in the lifetime risk of cancer is 1E-5 or 1 in 100,000.

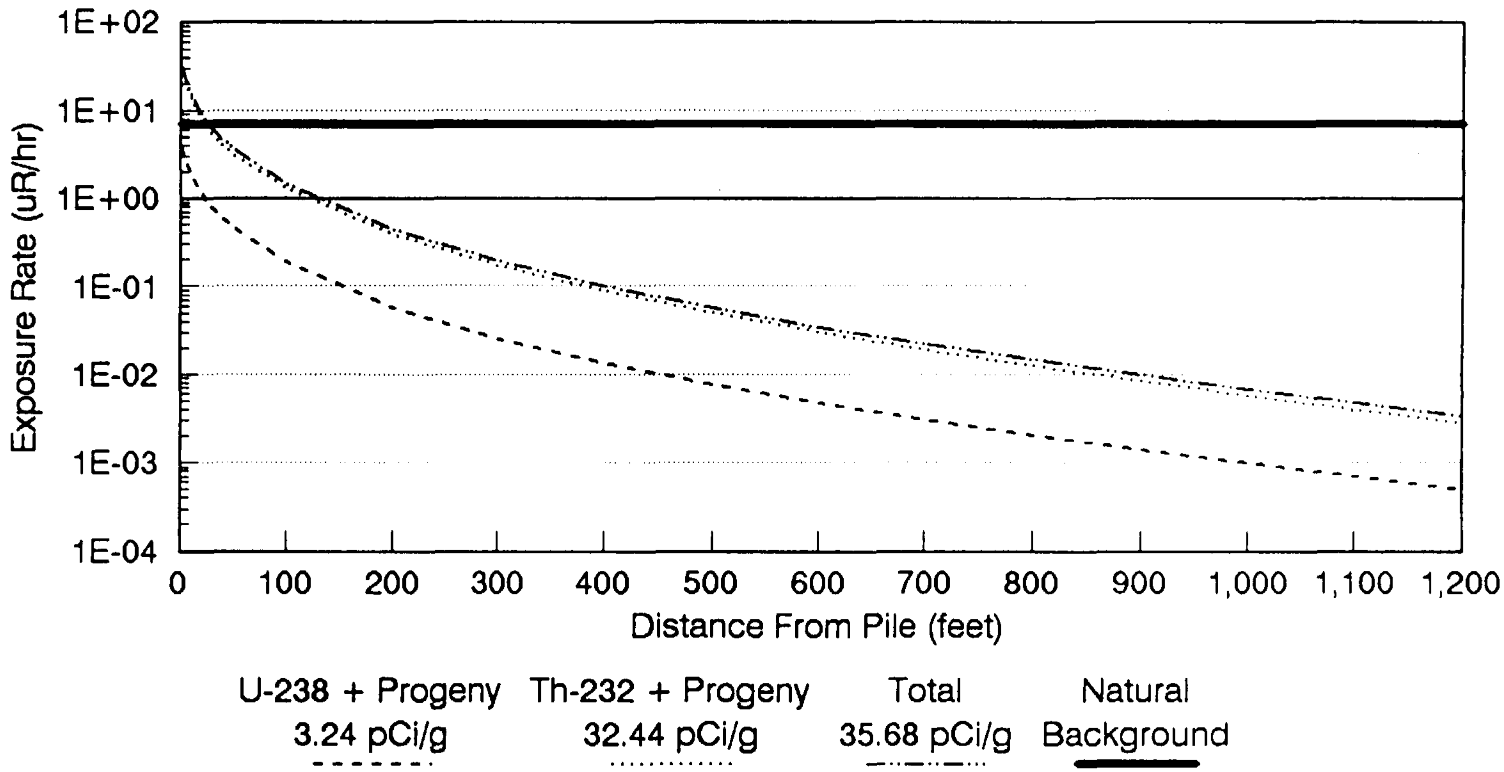
Exposure measurements are not available at the location of the residence; however, an additional 0.1 μR/hr from the new pile could constitute no more than an approximate 1 percent increase in the current external exposure rate and corresponding health risks.

The lifetime total risk of cancer due to external exposures from the new storage pile is less than 1E-6, the point of departure for determining remediation goals, at a distance of about 900 feet. The total exposure rate associated with this risk is 1E-2 μR/hr. The annual dose equivalent rate at 900 feet is 5.2E-2 mrem/yr.

3.4 UNCERTAINTY OF DOSE AND RISK RESULTS

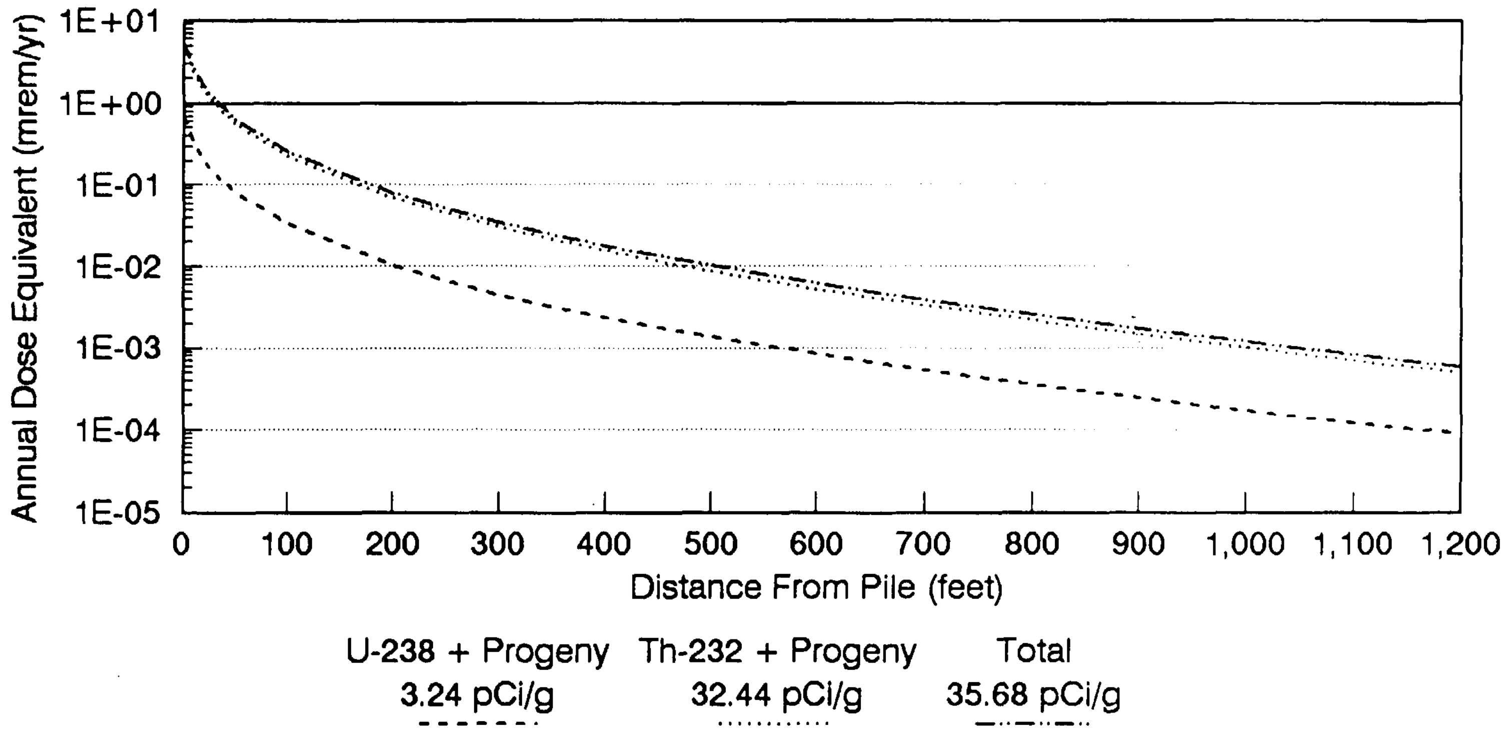
3.4.1 Uncertainty of Concentrations

There is uncertainty associated with the average concentration of the contamination assumed for the dirt pile. Only a single soil sample was taken at each property. Generally, samples are taken from a small area of a square foot or a fraction of a square foot and generally from a discrete depth of about 6 inches to 12 inches. The reality is that it is difficult to characterize contamination with a single sample. Also, only limited analyses were performed on the samples. The samples were generally analyzed by



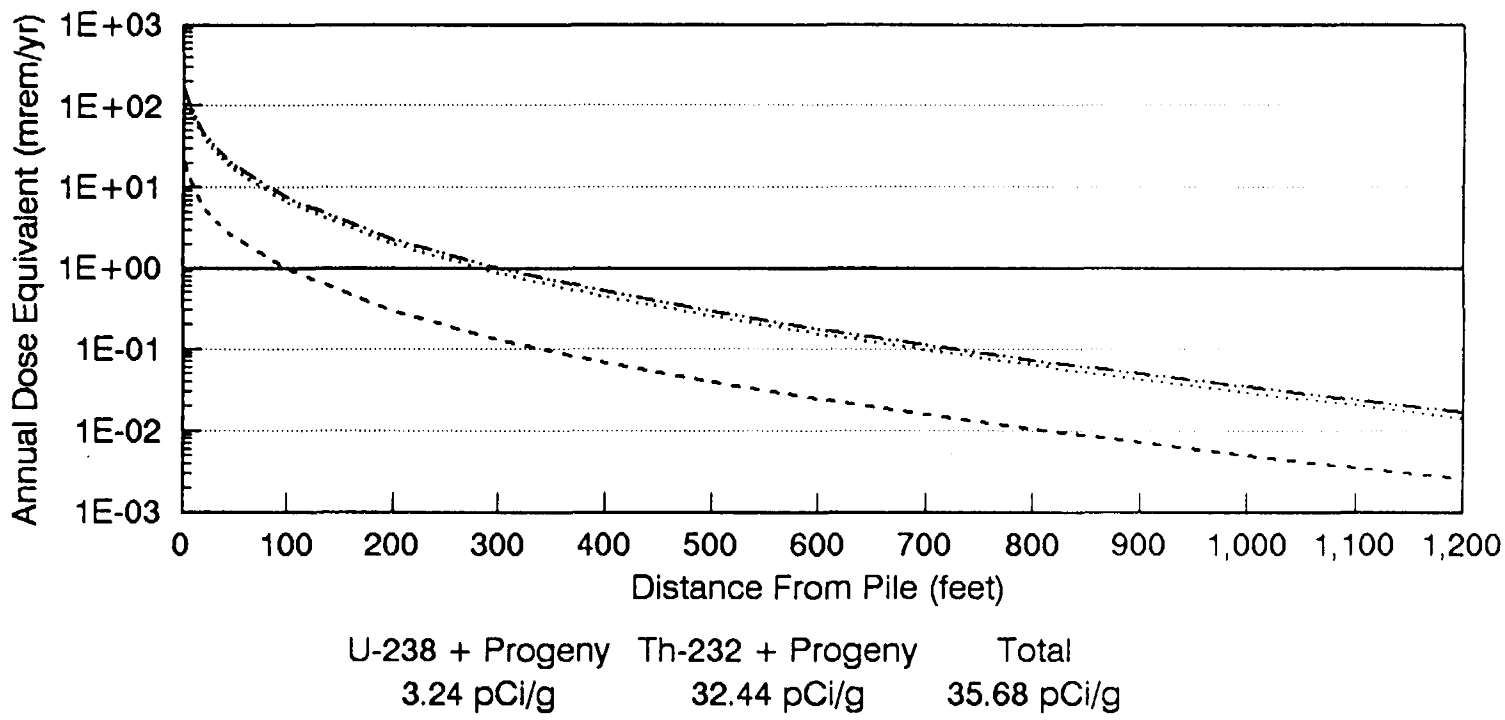
Based on exposure at 1 m (3.3 ft) above ground level. Soil density assumed to be 1.6 g/cc.

Figure 3-2. External Exposure Rate as a Function of Distance from a 226,130 Cubic Foot Hemisphere of Contaminated Soil



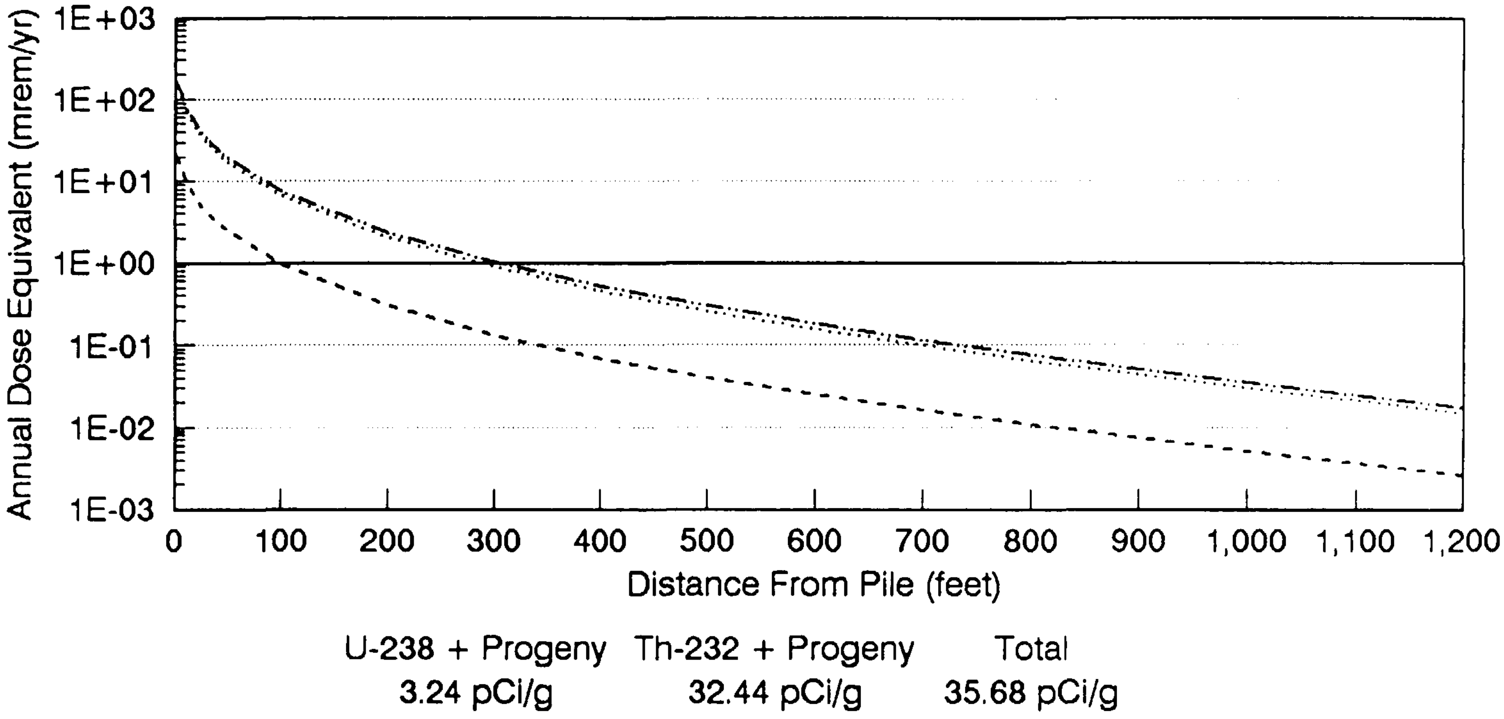
Exposure at 1 m (3.3 ft) above ground level.
Soil density assumed to be 1.6 g/cc.
Assumes 175 hrs/year spent outside at home.

Figure 3-3. Annual Outdoor Dose Equivalent as a Function of Distance from a 226,130 Cubic Foot Hemisphere of Contaminated Soil



Exposure at 1 m above ground level. Soil density equals 1.6 g/cc. Assumes 6,300 hrs/yr inside home. Shielding factor equals 0.8.

Figure 3-4. Annual Indoor Dose Equivalent as a Function of Distance from a 226,130 Cubic Foot Hemisphere of Contaminated Soil



Exposure 1 m (3.3 ft) above ground. Soil density equals 1.6 g/cc. Assumes 6300 hrs/yr inside & 175 hrs/yr outside. Shielding equals 0.8.

Figure 3-5. Annual Total Dose Equivalent as a Function of Distance from a 226,130 Cubic Foot Hemisphere of Contaminated Soil

Table 3-4. Risk as a Function of Distance from a 226,130 ft^3 Hemisphere of Contaminated Soil

Distance (feet)	Annual Total Cancer Risk[a]			Lifetime Total Cancer Risk[b]		
	U-238 + Progeny	Th-232 + Progeny	Total	U-238 + Progeny	Th-232 + Progeny	Total
1	1.3E-05	9.1E-05	1.0E-04	3.9E-04	2.7E-03	3.1E-03
5	9.7E-06	6.9E-05	7.8E-05	2.9E-04	2.1E-03	2.4E-03
10	6.4E-06	4.5E-05	5.1E-05	1.9E-04	1.4E-03	1.5E-03
15	4.8E-06	3.4E-05	3.8E-05	1.4E-04	1.0E-03	1.2E-03
20	3.8E-06	2.7E-05	3.0E-05	1.1E-04	8.0E-04	9.1E-04
25	3.1E-06	2.2E-05	2.5E-05	9.3E-05	6.5E-04	7.5E-04
30	2.6E-06	1.8E-05	2.1E-05	7.8E-05	5.5E-04	6.3E-04
35	2.2E-06	1.5E-05	1.8E-05	6.7E-05	4.6E-04	5.3E-04
40	2.0E-06	1.3E-05	1.5E-05	5.9E-05	4.0E-04	4.6E-04
45	1.7E-06	1.2E-05	1.4E-05	5.2E-05	3.6E-04	4.1E-04
50	1.5E-06	1.1E-05	1.2E-05	4.6E-05	3.2E-04	3.6E-04
100	6.1E-07	4.2E-06	4.8E-06	1.8E-05	1.3E-04	1.4E-04
200	1.9E-07	1.3E-06	1.5E-06	5.7E-06	3.8E-05	4.4E-05
300	8.4E-08	5.6E-07	6.4E-07	2.5E-06	1.7E-05	1.9E-05
400	4.4E-08	2.9E-07	3.3E-07	1.3E-06	8.6E-06	1.0E-05
500	2.5E-08	1.6E-07	1.9E-07	7.6E-07	4.9E-06	5.7E-06
600	1.6E-08	9.9E-08	1.1E-07	4.7E-07	3.0E-06	3.4E-06
700	1.0E-08	6.3E-08	7.3E-08	3.0E-07	1.9E-06	2.2E-06
800	6.8E-09	4.1E-08	4.8E-08	2.0E-07	1.2E-06	1.4E-06
900	4.6E-09	2.8E-08	3.2E-08	1.4E-07	8.3E-07	9.7E-07
1000	3.2E-09	1.9E-08	2.2E-08	9.7E-08	5.7E-07	6.6E-07
1100	2.3E-09	1.3E-08	1.5E-08	6.9E-08	4.0E-07	4.6E-07
1200	1.7E-09	9.3E-09	1.1E-08	5.0E-08	2.8E-07	3.3E-07

a. Based on 6.23E-04 total cancers per rad (EPA89b).
b. Assumes 30 years lifetime exposure.

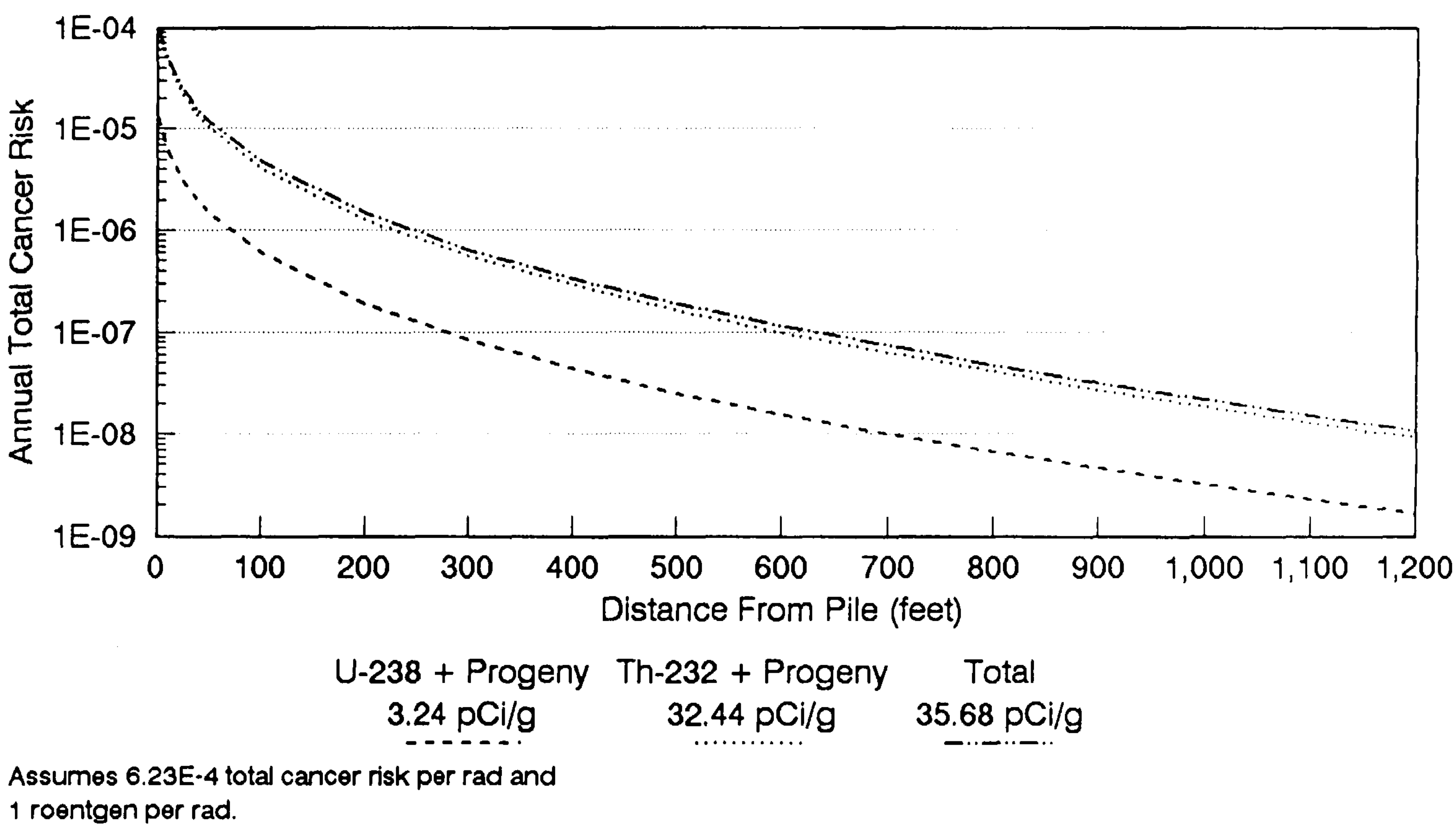


Figure 3-6. Annual Total Cancer Risk as a Function of Distance from a 226,130 Cubic Foot Hemisphere of Contaminated Soil

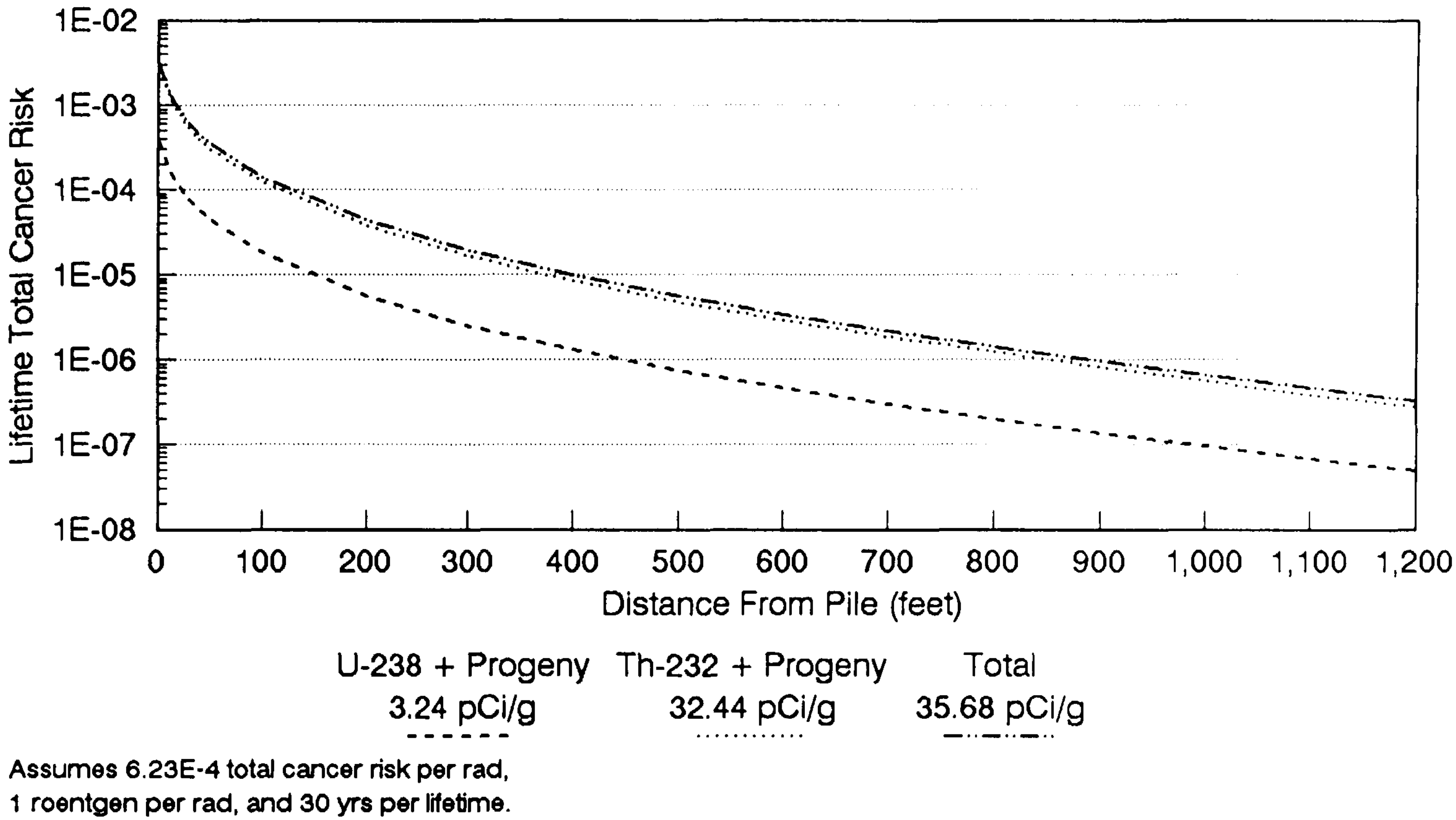


Figure 3-7. Lifetime Total Cancer Risk as a Function of Distance from a 226,130 Cubic Foot Hemisphere of Contaminated Soil

gamma spectroscopy. Results were only given for the radionuclides related to Ra-226 and Ra-228, radium isotopes from the U-238 and Th-232 decay chains. It is known that uranium and thorium were removed during the processing of ores at the Rare Earths Facility (EPA86), but since detailed analysis was not provided for the site survey samples, it was assumed all the radionuclides in the U-238 and Th-232 decay chains were present in secular equilibrium.

The soil samples were taken at the location of the maximum gamma radiation level for the property. Therefore, it is reasonable to assume that the concentration used to calculate the doses and risks for the contaminated dirt pile should represent an upper bound value and that the average concentration of the excavated dirt will be lower. However, it is possible that soil contaminated with a higher concentration of Th-232 and U-238 is currently covered by overburden or asphalt and as such was not sampled and that the average concentration of the excavated dirt will be higher. In either case, since the projected doses and risk are directly proportional to the concentration used in the calculations, the new values would be equal to the current values times the ratio of the actual concentration to the concentration assumed for this assessment.

3.4.2 Uncertainty of Volume of Excavated Contaminated Soil

The dose and risk assessment for the pile of contaminated soil is based on the volume of soil that is estimated will be removed from the seven properties included in this focused risk assessment. The number of contaminated properties is known to be larger and the list may grow as more properties are surveyed. Therefore, the exact volume cannot be estimated at this time.

When the volume of soil increases, the dose and risk values will also increase, but the increase will not be a simple multiplication. For example, if the volume of the pile were to be increased by a factor of five, the exposure at the west fence would increase from 4 μR/hr to 13 μR/hr. The increase in the exposure rate is approximately a factor of three. Most of this increase is due to the edge of the pile being closer to the fence. A smaller part of the increase is due to the factor of five increase in the total activity. In the later case, the volume increase effect is smaller because emissions from contaminated soil within the pile are shielded by soil on the outside of the pile. Most of the exposure is due to emissions from contaminated soil near the surface of the pile. The actual volume of the pile that contributes to the exposure does not increase significantly. Thus, the overall result of increasing the volume of the pile by a factor of five is an increase in the exposure rate by a factor of approximately three.

At the nearest residence, the exposure rate would increase from 0.10 μR/hr to 0.31 μR/hr, which again is a factor of three increase. This would principally be due to the increased volume since, at large distances, the exposure rate does not change greatly with increased distance from the pile. Even so, as stated in the paragraph above, the increase is not a straight multiple of the volume because of shielding by soil on the pile surface. It should be noted that even with an increase of a factor of three, the exposure rate at the nearest residence would still be only marginally discernable using conventional survey meters.

3.4.3 Uncertainty of Risk Parameters

The health risk parameters from the EPA HEAST tables (EPA92) were used for the inhalation and ingestion pathways and risk parameters from the EPA assessment for the Clean Air Act background documents of 1989 (EPA89) were used for assessing the external gamma exposures. These risk parameters are based on health effects that have been observed at radiation doses up to several orders of magnitude above the doses related to these sites. There is considerable uncertainty in extrapolating the observed health effects to the low dose levels associated with these activities. While there is some consideration that actual health effects may be higher than those projected with the subject risk factors, it is possible that actual health effects will be less (EPA89c).

3.4 REFERENCES

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APPENDIX A

RADON AND THORON EXPOSURE MODEL

APPENDIX A

MODEL FOR RADIATION EXPOSURE IN A CONTROL VOLUME FROM VARIOUS SOURCE AND SINKS OF RADON OR THORON

The concentration of radon or thoron gas within a confined living space is dependent upon several possible sources and sinks which determine and control the time dependent concentration. A flux of thoron or radon gas can diffuse into the living space from source materials (generally contaminated soil) surrounding the space or can undergo a convective exchange with an external volume such as the ambient environment or another adjacent space (e.g., a basement or crawl space). A mathematical model for such a generalized space is established here.

Consider a control volume V in which a time varying radioactive gas concentration T(t) of radon (Rn-222) or thoron (Rn-220) enters the control volume either as a

- radon/thoron flux which flows from an external source through an effective diffusion area A associated with the control volume V or as a

- concentration gradient from the ambient environment external to the control volume V as $\lambda_v (T_o - T)$ or as a

- concentration gradient from a crawl space volume V as $\lambda_{vc} (T_c - T)$.

The radon/thoron concentration in the control volume is reduced through radioactive decay as $\lambda_d T$. Figure 1 provides a schematic representation for the radiation exposure model indicating the sources and sinks of radon/thoron and the appropriate concentration volumes.

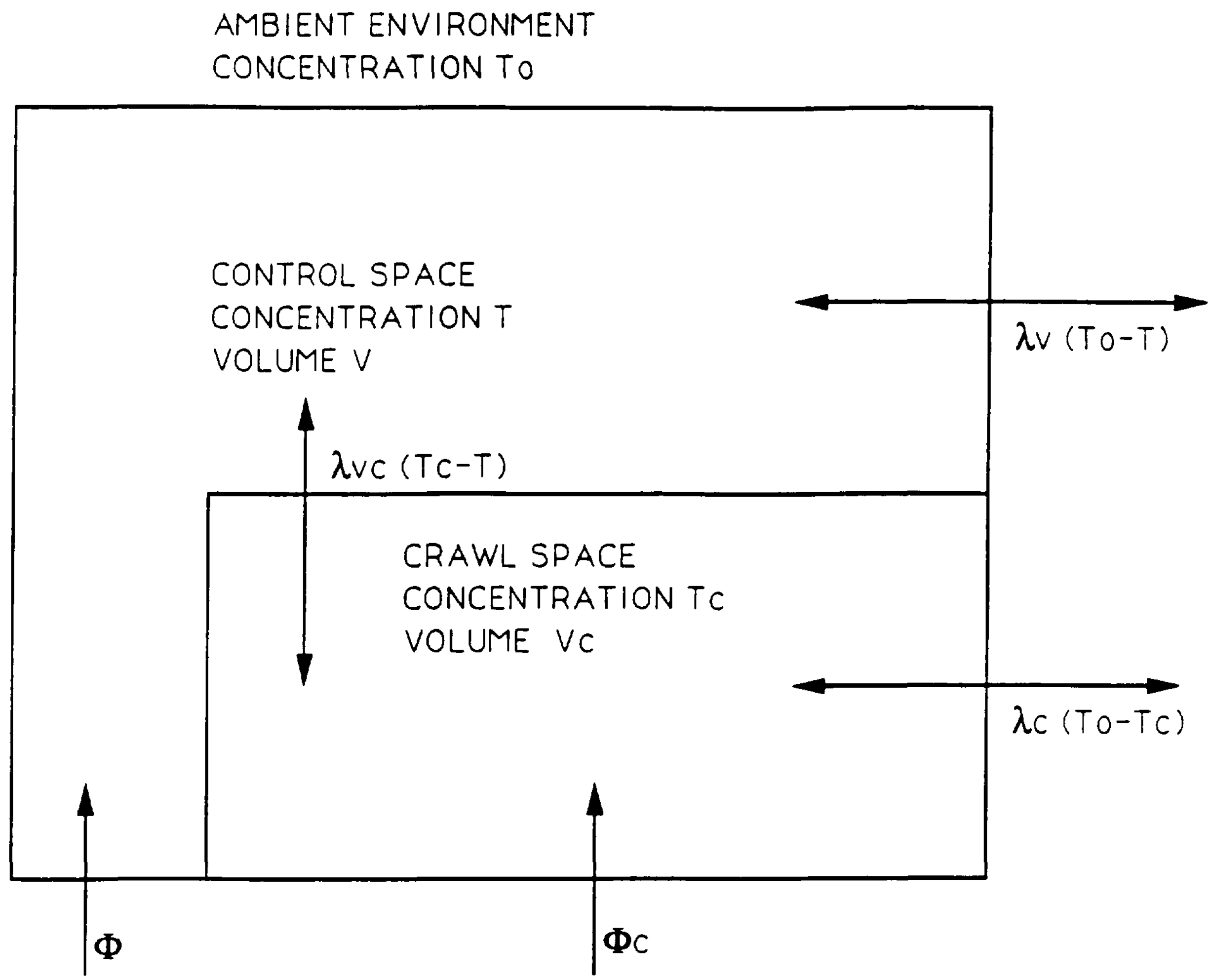

Figure A-1. Schematic Representation of the Model for Determining the Radon and Thoron Concentrations within a Control Volume

Spatial variation of the radon/thoron concentration in the control volume is ignored and only spatial averages for all model parameters and variables are considered. The basic time dependent differential equation which describes the time rate of change of radon/thoron within the control volume is given by

$$dT/dt = A\varnothing/V + \lambda_v(T_o - T) + \lambda_{vc}(T_c - T) - \lambda_d T \qquad (1)$$

where

$T(t)$ = The space averaged, time dependent radon/thoron concentration with the control volume V (pCi/m^3)

$T_o(t)$ = The space averaged, time dependent radon/thoron concentration in the ambient environment (pCi/m^3)

t = Time (hr)

A = The effective area through which the radon/thoron diffuses into the control volume (m^2)

V = The control volume (m^3)

λ_v = The effective time constant for exchange of radon/thoron between the control volume and the ambient environment (hr^{-1})

λ_{vc} = The effective time constant for exchange of radon/thoron between the control volume and the crawl space volume (hr^{-1})

λ_d = The radioactive decay constant for radon/thoron (hr^{-1})

$\varnothing$ = The net flux of radon/thoron entering the control volume V per unit area A (pCi/m^2-hr)

The time dependent differential equation which describes the time rate of change of radon/thoron within the crawl space volume is similar to equation (1) and is given by the following

$$dT_c/dt = A_c\varnothing_c/V_c + \lambda_v(T_o - T_c) + \lambda_{vc}(T - T_c) - \lambda_d T_c \qquad (2)$$

where

$T_c(t)$ = The space averaged, time dependent radon/thoron concentration within the crawl space volume V (pCi/m^3)

$T_o(t)$ = The space averaged, time dependent radon/thoron concentration within the ambient environment (pCi/m^3)

t = Time (hr)

A_c = The effective area through which the radon/thoron flows into the crawl space volume (m^2)

V_c = The crawl space volume (m^3)

λ_c = The effective time constant for exchange of radon/thoron between the crawl space volume V and the ambient environment (hr^{-1})

λ_{vc} = The effective time constant for exchange of radon/thoron between the control volume and the crawl space volume V_c (hr^{-1})

λ_d = The decay constant for radon/thoron (hr^{-1})

$\O_c$ = The net flux of radon/thoron entering the crawl space volume V_c per unit area A_c (pCi/m^2-hr)

At equilibrium conditions the asymptotic value of the radon/thoron concentration in the control volume and crawl space volume can be found from Equations (1) and (2). For the control volume the equilibrium thoron /radon concentration is given by

$$T = [\lambda_2 A\O/V + \lambda_{vc} A_c \O_c/V_c + T_o(\lambda_2\lambda_v + \lambda_c\lambda_{vc})]/(\lambda_1\lambda_2 - \lambda_{vc}^2) \quad (3)$$

Similarly,. for the crawl space volume the asymptotic concentration is given by

$$T_c = [\lambda_{vc} A\O/V + \lambda_1 A_c \O_c/V_c + T_o(\lambda_{vc}\lambda_v + \lambda_1\lambda_c)]/(\lambda_1\lambda_2 - \lambda_{vc}^2) \quad (4)$$

where

$$\lambda_1 = \lambda_{vc} + \lambda_d + \lambda_v$$

$$\lambda_2 = \lambda_{vc} + \lambda_d + \lambda_c$$

Observe that in the absence of a crawl space adjacent to the control volume, then $\lambda_{vc} = \lambda_c = 0$ and equation (3) for the asymptotic radon/thoron concentration in the control volume reduces to the following expression

$$T = [\, AØ/V + \lambda_v T_o] \,/\, (\lambda_v + \lambda_d) \tag{5}$$

Furthermore, observe that the proportionality factor between the asymptotic control volume concentration and the concentration in the ambient environment (e.g. outside atmosphere) is given by $\lambda_v/(\lambda_v + \lambda_d)$ since

$$T/T_o = [\, 1 + AØ/(\lambda_v T_o V)\,]\ \lambda_v \,/\, (\lambda_v + \lambda_d) \tag{6}$$

Thus the concentration of radon/thoron encountered in a simple control space (i.e., a control space for which no adjacent spaces contribute to the control space concentration) is proportional to $\lambda_v/(\lambda_v + \lambda_d)$.

SAMPLE CALCULATION FOR INDOOR RADON AND THORON

The equilibrium or asymptotic value of the radon or thoron concentration in the control volume is given by equation (3)

$$T = [\lambda_2 A\text{Ø}/V + \lambda_{vc} A_c \text{Ø}_c / V_c + T_o(\lambda_2\lambda_v + \lambda_c\lambda_{vc})] / (\lambda_1\lambda_2 - \lambda_{vc}^2) \quad (3)$$

Similarly, for the crawl space volume the equilibrium concentration is given by equation (4)

$$T_c = [\lambda_{vc} A\text{Ø}/V + \lambda_1 A_c \text{Ø}_c / V_c + T_o(\lambda_{vc}\lambda_v + \lambda_1\lambda_c)] / (\lambda_1\lambda_2 - \lambda_{vc}^2) \quad (4)$$

Pertinent values for the parameters for the thoron concentration are

λ_d = 44.9 hr^{-1} - thoron radioactive decay constant

λ_v = 1.0 hr^{-1} - air volume exchange rate between the ambient air and the control volume V

λ_c = 2.0 hr^{-1} - air volume exchange rate between the crawl space and the ambient air

λ_{vc} = 1.0 hr^{-1} - air volume exchange rate between the crawl space and the control volume

$\lambda_1 = \lambda_{vc} + \lambda_d + \lambda_v = 46.9\ (hr^{-1})$

$\lambda_2 = \lambda_{vc} + \lambda_d + \lambda_c = 47.9\ (hr^{-1})$

A_c/V_c = 2.0 m^{-1} - thoron diffusion area into the crawl space divided by the crawl space volume (assumes a crawl space height of 0.5 m)

It is further assumed that no thoron enters the control volume directly from the soil and that the ambient thoron concentration is negligible so

$\varnothing = T_o = 0$

and thus a value for A/V need not be assigned in equation (3) since $\varnothing = 0$.

For typical soils containing thorium the relationship between thoron soil concentration and soil flux is (see chapter 2 for discussion) :

1 pCi/g in soil = 90 pCi/m^2-s or 3.24 x 10^5 pCi/m^2-hr as the soil flux

So the thoron flux from the soil entering into the crawl space arising from a soil concentration of 1 pCi/g is

$\varnothing_c$ = 3.24 x 10^5 pCi/m^2-hr - thoron soil flux

From equation (3) the thoron concentration level in the control volume is found to be

T = 0.29 pCi/L

The thoron daughter concentration is assumed to be at 3% of equilibrium (St80,Za86 in chapter 2). The working level associated with the concentration of thoron daughters, assuming a soil concentration of 1 pCi/g of thorium at equilibrium conditions and 75% occupancy (for a full year) is:

WL(thoron daughters) = 0.29 pCi/L (thoron) x

1 WL(thoron) /7.4 pCi/L(thoron) x .03 (fraction equilibrium)

x 0.75 (occupancy factor) = 8.8 x 10^{-4} WL

Pertinent values for the parameters for the radon concentration are

λ_d = 7.63×10^{-3} hr^{-1} - radon radioactive decay constant

λ_v = 1.0 hr^{-1} - air volume exchange rate between the ambient air and the control volume V

λ_c = 2.0 hr^{-1} - air volume exchange rate between the crawl space and the ambient air

λ_{vc} = 1.0 hr^{-1} - air volume exchange rate between the crawl space and the control volume

λ_1 = $\lambda_{vc} + \lambda_d + \lambda_v = 2.01 (hr^{-1})$

λ_2 = $\lambda_{vc} + \lambda_d + \lambda_c = 3.01\ (hr^{-1})$

A_c/V_c = 2.0 m^{-1} - radon diffusion area into the crawl space divided by the crawl space volume (assumes a crawl space height of 0.5 m)

It is further assumed that no radon enters the control volume directly from the soil and that the ambient radon concentration is negligible so

$$\text{Ø} = T_o = 0$$

and thus a value for A/V need not be assigned in equation (3) since Ø = 0.

For typical soils containing radium in distributions with depth similar to that for the remediation criteria the relationship between radon soil concentration and soil flux is (see text in chapter 2)

$$1 \text{ pCi/g in soil} = 0.4 \text{ pCi/m}^2\text{-s} \text{ or } 1.4 \times 10^3 \text{ pCi/m}^2\text{-hr as the soil flux}$$

So the radon flux from the soil entering into the crawl space arising from a soil concentration of 1 pCi/g of Ra-226 is

$\emptyset_c = 1.4 \times 10^3$ pCi/m^2-hr - radon soil flux

From equation (3) the radon concentration level in the control volume is found to be

T = 0.57 pCi/L

The radon daughter concentration is assumed to be at 50% of equilibrium. The working level associated with the concentration of radon daughters, assuming a soil concentration of 1 pCi/g at equilibrium conditions and 75% occupancy (for a full 365-day year), is found to be

WL(radon daughters) = 0.57 pCi/L (radon) x

1 WL(radon) /100 pCi/L(radon) x 0.5 WL(radon daughters) /1 WL(radon)

x 0.75 (occupancy factor) = 2.1×10^{-3} WL

APPENDIX B

RISK ASSESSMENTS

APPENDIX B

RISK ASSESSMENTS

B.1 INTRODUCTION

This appendix provides additional information on the dose and health effects parameters used in calculating the risks for the West Chicago Rare Earths Facility off-site properties.

B.2 DOSE AND HEALTH EFFECTS PARAMETERS

Table B-1 presents the dose conversion and cancer morbidity factors used in this assessment for the inhalation and ingestion exposure pathways. The risk estimates are based on the EPA HEAST slope factors (EPA92). The HEAST values, which are for the average population, are in terms of risk per unit activity.

The radon risk is based on the risk assessment procedures proposed by the EPA Science Advisory Board in 1992. The risk parameter used is 224 per million WLM of exposure. The thoron risk value is 180 per million WLM of exposure (EPA86). These risk parameters are only for mortality and do not include morbidity. Inclusion of morbidity would increase the risk parameters by about 10 percent, since lung cancer has about a 90 percent fatality rate (Am91).

Risk parameters from the EPA assessment for the Clean Air Act background documents of 1989 (EPA89) were used for assessing the external gamma exposures. The lifetime averaged risk factor, 6.23E-4 risk per rad, was used for adults. The risk factor for ages 10 through 19, 1.386E-3 risk per rad, was used for teenagers and the risk factor for ages 0-9, 1.434E-3 risk per rad, was used for children. The risk factors include both mortality and morbidity.

B.3 PATHWAYS ASSESSMENT

B.3.1 Inhalation and Ingestion Pathways

Generic inhalation and ingestion pathway risk conversion factors were developed for each radionuclide assuming a 1 pCi/g concentration of that radionuclide in the soil. The input parameters are presented in Tables B-1 through B-2. Intermediate results are presented in Tables B-3 and B-4. The results of these calculations are presented in Table B-5. These results were then combined with property specific data to calculate the risks presented in Table B-7.

Table B-1 presents the radionuclide dependent dose conversion and cancer morbidity factors used in this assessment. The radionuclide independent parameters are given in Table B-2 for the inhalation, soil ingestion, and food ingestion pathways.

Table B-3 provides a tabulation of the concentrations for each radionuclide of the U-238 and Th-232 radioactive decay chains for the various media considered for the inhalation and ingestion pathways. The base concentration is 1 pCi/g in soil for each radionuclide. The concentrations in the various media are calculated from this base. For example, Table 2 shows that a dust loading of 0.216 $\mu g/m^3$ is assumed. The airborne concentrations are calculated by multiplying this dust loading by the soil concentration of 1 pCi/g for each radionuclide.

The concentrations of radionuclides in vegetation are calculated by multiplying the soil concentration by the Biological Concentration Factors (BCFs). The BCF's are also presented in Table B-3. The BCF parameters in Table B-3 are based on information from Baes et al., "A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture," ORNL-5786, 1984. The factors in Baes et al. are based on the dry weight of vegetation, and have been modified to reflect the wet or fresh weight of vegetation. The BCF factors in Table B-2 are based on the long half-life parent radionuclides. For example, the presence of Th-234 and Pa-234m, short half-life decay products of U-238, in vegetation is based on the transfer of U-238 to the vegetation and the subsequent radioactive ingrowth of the Th-234 and Pa-234m in the vegetation. However, to be conservative and to account for any Th-234 and Pa-234m that is directly transferred to vegetation, they are assumed to be at secular equilibrium with U-238 in the vegetation and the time delay required for radioactive ingrowth is not calculated. This example portrays how the other groups of radionuclides were handled for the selection of BCFs.

The intake activity, presented in Table B-4, is determined using the concentration in the specific media (Table B-3) in combination with parameters from Table B-2. The following are the equations.

<u>Inhalation of Outdoor Particulates for 30 years:</u>

Activity Inhaled in pCi = (air concentration in pCi/m^3) * (breathing rate in m^3/hour) * (exposure rate in hours/day) * (exposure period in days)

The intake activity for the inhalation of outdoor particulates is based on an adult of 70 kg breathing 1 cubic meter/hour. It is assumed that the ratio of breathing rate and body weight for a child and teenager would be similar. Furthermore, this pathway results in a very small fraction of the health risk.

Soil Ingestion:

Activity Ingested in pCi = (soil concentration in pCi/g) *
(soil intake rate in g/day) *
(exposure period in days)

where both the intake rate and exposure period are age group and scenario dependent. These values are given in Table B-2. The exposure duration times are 24 years for adult ingestion of soil, 2 years and 4 years for the two scenarios for teenage ingestion of soil, and 4 years and 6 years for the two scenarios for child ingestion of soil. A child in assumed to ingest 0.2 g/day of soil. A teenager or adult is assumed to ingest 0.1 g/day of soil.

Ingestion of Fruit and Vegetables for 30 years:

Activity Ingested in pCi = (soil concentration in pCi/g) *
[(vegetable intake rate of 200 g/day) *
(vegetable diet fraction of 0.4) +
(fruit intake rate of 140 g/day) *
(fruit diet fraction of 0.3)] *
(exposure period of 10,500 days)

Table B-5 provides the dose and risk per unit concentration in the soil for the ingestion and inhalation pathways. The values were calculated using the intake of designated picocuries from Table B-4 and slope factors from the appropriate column of Table B-1.

B.3.2 Exposure to Direct Gamma Radiation

For the present land use scenarios, the risks are based on the maximum net (measured minus natural background) gamma exposure rate reported for each property. For the future unrestricted land use scenarios, the gamma exposures were calculated using the MicroShield computer code (Grove Engineering, Maryland), based on the Th-232 and U-238 concentrations in the contaminated soil and shielding due to the wood floor or over-burden soil as appropriate. The indoor gamma exposure include the shielding effect of a 2 inch thick wood floor (i.e., reduction to 75 percent of unshielded exposure). The contaminated areas were modeled as two foot thick cylinders having radii ranging from 16 to 33 feet. The soil was modeled as water with a density of 1.6 g/cc. Taylor buildup factors based on the water material were applied.

B.4 RISK ASSESSMENTS FOR WEST CHICAGO PROPERTIES

The health risk assessment results from Table B-5 are used with property and scenario specific information to provide health risk assessments for the specified properties. Property specific information includes current soil concentrations and measured exposure data. The gamma exposure rates are the maximum net (minus natural background) values for each property. Generally, only the maximum value was reported by the site investigator. The soil concentrations are based on one soil sample from each property taken from the area with the highest outdoor gamma exposure rate measurement. The soil concentration obtained from that single soil sample was assumed to apply uniformly to the contaminated area on that property. For each property, adjustment factors were applied to this conservative assumption to reduce the exposure for certain pathways depending upon the property characteristics. These adjustment factors are presented in Table B-6.

The health risk results from Table B-5 were combined with the property specific data, the pathway adjustment factors, and the exposure duration assumptions to calculate the property specific risks. The results of the assessments for the present and future land use scenarios are presented in Tables B-7 and B-8. In addition to total risks, subtotals are provided for gamma exposures and inhalation and ingestion pathways exposures. Summaries of these results are presented in the Section 2.0.

The ingestion, inhalation, and direct gamma exposure adjustment factors are based on the size of the areas of contamination on the properties (see Table 2 of Section 2.0). In Table B-6, factors are presented for both the present and future unrestricted land use scenarios.

The direct gamma exposure adjustment factors used for the present use scenarios are generally one (1) except for Residence # 5. At this property, the area of contamination is by a septic tank. It was judged to be so small, compared to the rest of the property, that only 50 percent of the outside exposure was assumed to occur at that location.

Future use adjustment factors include a food factor and an indoor gamma exposure factor. The future use food adjustment factor is similar to the present use food factor except that consideration is given to possible spreading of contamination (i.e., a larger contaminated area is assumed to be available for use in growing fruit and vegetables) and the presence of gardens at future residences built on what are now school properties. Both indoor and outdoor gamma exposure pathways were included in the future unrestricted land use scenarios. An adjustment factor related to the size of the area of contamination was applied to the indoor gamma exposures. No adjustment factors were applied to outdoor gamma exposure pathway risks. In general, the areas of contamination (see Table 2 in Section 2.0) are too small to provide a significant outdoor gamma exposure if it is assumed that a house is built over the contamination. However, this pathway was included since, as a result of regrading of the contaminated soil during construction, it would still be possible to be exposed to direct gamma radiation while performing outdoor activities.

Both the present and future unrestricted use scenarios use adjustment factors for the inhalation of outdoor airborne particulates. The adjustment factors for this pathway are based on the size of the area of contamination and isolation of the contamination by soil or asphalt. Even when the contamination appeared to be covered, it was assumed there would be inhalation of resuspended material. The intention was to be conservative but to also account for the isolation of the material. The degree of present isolation of the material is based on the relationship of the concentrations of contaminates in the soil and the measured gamma exposure rates (see Table 2 in Section 2.0).

B.5 REFERENCES

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Ec88 — Eckerman, K.F., Wolbarst, A.B., and Richardson, A.C.B., "Limiting Values of Radionuclide Intake and air concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, DC 20460.

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EPA92 — U.S. Environmental Protection Agency, "Health Effects Assessment Summary Tables," Office of Solid Waste and Emergency Response, OERR 9200 6-303 (90-3), P890-921100, 1992 (In Press).

Table B-1. Cancer morbidity factors[a].

Nuclide	Ingestion Slope Factor (1/pCi)	Inhalation Slope Factor (1/pCi)
U-238	1.60E-11	2.40E-08
Th-234	4.00E-12	3.20E-11
Pa-234m	5.80E-15	1.60E-15
U-234	1.60E-11	2.60E-08
Th-230	1.30E-11	2.90E-08
Ra-226	1.20E-10	3.00E-09
Rn-222	1.40E-12	7.30E-13
Po-218	2.80E-14	5.80E-13
Pb-214	1.70E-13	2.90E-12
Bi-214	1.30E-13	2.10E-12
Po-214	1.00E-20	2.80E-19
Pb-210	5.10E-10	1.30E-09
Bi-210	1.60E-12	8.00E-11
Po-210	1.50E-10	2.60E-09
Th-232	1.20E-11	2.80E-08
Ra-228	1.00E-10	6.60E-10
Ac-228	5.00E-13	2.60E-11
Th-228	1.10E-11	7.70E-08
Ra-224	3.80E-11	1.20E-09
Rn-220	0.00E+00	1.20E-13
Po-216	3.00E-17	4.80E-16
Pb-212	5.50E-12	4.30E-11
Bi-212	3.10E-13	6.60E-12
Po-212	2.20E-23	6.10E-22
Tl-208	1.80E-14	5.10E-15

a The slope factors were taken from EPA92.

Table B-2. Pathway parameters.

Parameter	Units	Value	Reference
<u>Inhalation of Suspended Particulates (Outdoors):</u>			
Arborne Mass Loading	$\mu g/m^3$	2.16E-01	EPA91b
Inhalation rate	m^3/hr	8.30E-01	EPA91b
Exposure Rate			
Present Use			
School #1	hr/dy	2.00E+00	assumed
School #2	hr/dy	3.00E+00	assumed
School #3	hr/dy	3.00E+00	assumed
Residences	hr/dy	5.00E-01	EPA91a
Exposure Frequency			
Present Use			
School #1	dy/yr	1.95E+02	assumed
School #2	dy/yr	1.30E+02	assumed
School #3	dy/yr	1.30E+02	assumed
Residences	dy/yr	3.50E+02	EPA91a
Exposure Duration			
Present Use			
Child			
School #1	yr	4.00E+00	assumed
School #2	yr	2.00E+00	assumed
School #3	yr	4.00E+00	assumed
Teacher	yr	2.50E+01	assumed
Residences	yr	3.00E+01	EPA91a
Exposure Period[a]			
Present Use			
School #1			
Child	dy	7.80E+02	calculated
Teacher	dy	4.88E+03	calculated
School #2			
Child	dy	2.60E+02	calculated
Teacher	dy	3.25E+03	calculated
School #3			
Child	dy	5.20E+02	calculated
Teacher	dy	3.25E+03	calculated
Residences	dy	1.05E+04	calculated
<u>Ingestion of Soil:</u>			
Soil Concentration	pCi/g	Tables B-7&8	-
Soil Consumption Rate			
Child	g/d	2.00E-01	EPA91a
Teenager	g/d	1.00E-01	EPA91a
Teacher	g/d	5.00E-02	EPA91b
Adult at Residence	g/d	1.00E-01	EPA91a

Table B-2. Pathway parameters (continued).

Parameter	Units	Value	Reference
Exposure Frequency:			
Present Use			
School #1	dy/yr	1.95E+02	assumed
School #2	dy/yr	1.30E+02	assumed
School #3	dy/yr	1.30E+02	assumed
Residences	dy/yr	3.50E+02	EPA91a
Exposure Duration			
Present Use			
School #1	yr	4.00E+00	assumed
School #2	yr	2.00E+00	assumed
School #3	yr	4.00E+00	assumed
Residences			
Child (0-6 yr)	yr	6.00E+00	EPA91a
Adult	yr	2.40E+01	EPA91a
Exposure Period			
Present Use			
School #1	d	7.80E+02	calculated
School #2	d	2.60E+02	calculated
School #3	d	5.20E+02	calculated
Residences			
Child (0-6 yr)	d	2.10E+03	calculated
Adult	d	8.40E+03	calculated
<u>Ingestion of Vegetables and Fruit:</u>			
Vegetable Concentration	pCi/g	Table B-3	-
Fruit Concentration	pCi/g	Table B-3	-
Ingestion Rate:			
Vegetables	g/d	2.00E+02	EPA91a
Fruit	g/d	1.40E+02	EPA91a
Diet Fraction:			
Vegetables	-	4.00E-01	EPA91a
Fruit	-	3.00E-01	EPA91a
Exposure Frequency	d/yr	3.50E+02	EPA91a
Exposure Duration	yr	3.00E+01	EPA91a
Exposure Period	d	1.05E+04	EPA91a
<u>External Gamma Exposure:</u>			
Exposure Rate			
Present Use			
School #1	hr/dy	2.00E+00	assumed
School #2	hr/dy	3.00E+00	assumed
School #3	hr/dy	3.00E+00	assumed
Residences	hr/dy	5.00E-01	EPA91a
Exposure Frequency			
Present Use			
School #1	dy/yr	1.95E+02	assumed
School #2	dy/yr	1.30E+02	assumed
School #3	dy/yr	1.30E+02	assumed
Residences	dy/yr	3.50E+02	EPA91a

Table B-2. Pathway parameters (continued).

Parameter	Units	Value	Reference
Exposure Duration			
Present Use			
Child			
School #1	yr	4.00E+00	assumed
School #2	yr	2.00E+00	assumed
School #3	yr	4.00E+00	assumed
Teacher	yr	2.50E+01	assumed
Residences	yr	3.00E+01	EPA91a
Exposure Period[a]			
Present Use			
School #1			
Child	dy	7.80E+02	calculated
Teacher	dy	4.88E+03	calculated
School #2			
Child	dy	2.60E+02	calculated
Teacher	dy	3.25E+03	calculated
School #3			
Child	dy	5.20E+02	calculated
Teacher	dy	3.25E+03	calculated
Residences	dy	1.05E+04	calculated

a. Exposure Period = Exposure Frequency * Exposure Duration.

Table B-3. Media concentrations.

Nuclides	Soil Concentrations (pCi/g)	Vegetable BCF[a]	Fruit and Grain BCF[a]	Air Concentrations Particulates[b] (pCi/m^3)	Vegetable Concentrations Conc.[c] (pCi/g)	Fruit & Grain Concentrations[c] (pCi/g)
U-238	1.0	1.50E-03	5.10E-04	2.16E-07	1.50E-03	5.10E-04
Th-234	1.0	1.50E-03	5.10E-04	2.16E-07	1.50E-03	5.10E-04
Pa-234m	1.0	1.50E-03	5.10E-04	2.16E-07	1.50E-03	5.10E-04
U-234	1.0	1.50E-03	5.10E-04	2.16E-07	1.50E-03	5.10E-04
Th-230	1.0	1.50E-04	5.10E-05	2.16E-07	1.50E-04	5.10E-05
Ra-226	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Rn-222	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Po-218	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Pb-214	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Bi-214	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Po-214	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Pb-210	1.0	8.10E-03	5.40E-03	2.16E-07	8.10E-03	5.40E+03
Bi-210	1.0	8.10E-03	5.40E-03	2.16E-07	8.10E-03	5.40E+03
Po-210	1.0	8.10E-03	5.40E-03	2.16E-07	8.10E-03	5.40E+03
Th-232	1.0	1.50E-04	5.10E-05	2.16E-07	1.50E-04	5.10E-05
Ra-228	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Ac-228	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Th-228	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Ra-224	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Rn-220	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Po-216	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Pb-212	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Bi-212	1.0	2.70E-03	9.00E-04	2.16E-07	2.70E-03	9.00E-04
Po-212	0.64	2.70E-03	9.00E-04	1.38E-07	1.73E-03	5.76E-04
Tl-208	0.36	2.70E-03	9.00E-04	7.78E-08	9.72E-04	3.24E-04

a. Bioaccumulation factor (BCF) values derived from Baes et al., "A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture," ORNL-5786, 1984.

b. Particulate air concentration = soil concentration in pCi/g * airborne mass loading of 2.16E-7 g/m^3.

c. Vegetable concentration = soil concentration * vegetable BCF.
Fruit and grain concentration equals soil concentration * fruit and grain BCF.

Table B-4. Intake activity based on 1 pCi/g in soil.

Nuclide	Ingestion of Fruit & Veg. for 30 yrs (pCi)	Inhalation of Particulates Schools 2 years (pCi)	Schools 4 years (pCi)	Schools 25 years (pCi)	Residence 30 years (pCi)
U-238	1.48E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Th-234	1.48E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Pa-234m	1.48E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
U-234	1.48E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Th-230	1.48E+02	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Ra-226	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Rn-222	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Po-218	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Pb-214	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Bi-214	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Po-214	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Pb-210	9.19E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Bi-210	9.19E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Po-210	9.19E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Th-232	1.48E+02	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Ra-228	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Ac-228	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Th-228	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Ra-224	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Rn-220	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Po-216	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Pb-212	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Bi-212	2.66E+03	1.40E-04	2.81E-04	1.76E-03	9.45E-04
Po-212	1.71E+03	8.99E-05	1.80E-04	1.12E-03	6.05E-04
Tl-208	9.59E+02	5.05E-05	1.01E-04	6.32E-04	3.40E-04

Table B-4. Intake activity based on 1 pCi/g in soil (continued).

	Soil Ingestion					
Nuclide	Child for 6 years (pCi)	Child for 4 years (pCi)	Teenager for 2 years (pCi)	Teenager for 4 years (pCi)	Adult for 24 years (pCi)	Adult for 25 years (pCi)
U-238	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Th-234	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Pa-234m	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
U-234	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Th-230	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Ra-226	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Rn-222	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Po-218	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Pb-214	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Bi-214	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Po-214	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Pb-210	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Bi-210	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Po-210	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Th-232	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Ra-228	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Ac-228	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Th-228	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Ra-224	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Rn-220	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Po-216	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Pb-212	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Bi-212	4.20E+02	1.56E+02	2.60E+01	5.20E+01	8.40E+02	4.38E+02
Po-212	2.69E+02	9.98E+01	1.66E+01	3.33E+01	5.38E+02	2.80E+02
Tl-208	1.51E+02	5.62E+01	9.36E+00	1.87E+01	3.02E+02	1.58E+02

Table B-5. Risks per pCi/g in soil.

Nuclide	Ingestion of Fruit & Veg. for 30 yrs (pCi)	Inhalation of Outdoor Particulates Schools 2 Years (pCi)	Schools 4 Years (pCi)	Schools 25 Years (pCi)	Residence 30 Years (pCi)
U-238	2.38E-08	3.37E-12	6.74E-12	4.21E-11	2.27E-11
Th-234	5.94E-09	4.49E-15	8.99E-15	5.62E-14	3.02E-14
Pa-234m	8.61E-12	2.25E-19	4.49E-19	2.81E-18	1.51E-18
U-234	2.38E-08	3.65E-12	7.30E-12	4.56E-11	2.46E-11
Th-230	1.93E-09	4.07E-12	8.14E-12	5.09E-11	2.74E-11
Ra-226	3.20E-07	4.21E-13	8.42E-13	5.26E-12	2.83E-12
Rn-222	3.73E-09	1.02E-16	2.05E-16	1.28E-15	6.90E-16
Po-218	7.46E-11	8.14E-17	1.63E-16	1.02E-15	5.48E-16
Pb-214	4.53E-10	4.07E-16	8.14E-16	5.09E-15	2.74E-15
Bi-214	3.46E-10	2.95E-16	5.90E-16	3.69E-15	1.98E-15
Po-214	2.66E-17	3.93E-23	7.86E-23	4.91E-22	2.65E-22
Pb-210	4.68E-06	1.83E-13	3.65E-13	2.28E-12	1.23E-12
Bi-210	1.47E-08	1.12E-14	2.25E-14	1.40E-13	7.56E-14
Po-210	1.38E-06	3.65E-13	7.30E-13	4.56E-12	2.46E-12
Th-232	1.78E-09	3.93E-12	7.86E-12	4.91E-11	2.65E-11
Ra-228	2.66E-07	9.27E-14	1.85E-13	1.16E-12	6.24E-13
Ac-228	1.33E-09	3.65E-15	7.30E-15	4.56E-14	2.46E-14
Th-228	2.93E-08	1.08E-11	2.16E-11	1.35E-10	7.28E-11
Ra-224	1.01E-07	1.68E-13	3.37E-13	2.11E-12	1.13E-12
Rn-220	0.00E+00	1.68E-17	3.37E-17	2.11E-16	1.13E-16
Po-216	7.99E-14	6.74E-20	1.35E-19	8.42E-19	4.54E-19
Pb-212	1.47E-08	6.04E-15	1.21E-14	7.55E-14	4.06E-14
Bi-212	8.26E-10	9.27E-16	1.85E-15	1.16E-14	6.24E-15
Po-212	3.75E-20	5.48E-26	1.10E-25	6.85E-25	3.69E-25
Tl-208	1.73E-11	2.58E-19	5.16E-19	3.22E-18	1.74E-18
TOTAL U-238	6.46E-06	1.21E-11	2.42E-11	1.51E-10	8.13E-11
TOTAL Th-232	4.16E-07	1.50E-11	3.00E-11	1.88E-10	1.01E-10
TOTAL Ra-226	6.40E-06	9.81E-13	1.96E-12	1.23E-11	6.60E-12
Th-232+0.1U-238	1.06E-06	1.62E-11	3.24E-11	2.03E-10	1.09E-10

Table B-5. Risks per pCi/g in soil (continued).

Nuclide	Soil Ingestion Child for 6 years (pCi)	Child for 4 years (pCi)	Teenager for 2 years (pCi)	Teenager for 4 years (pCi)	Adult for 24 years (pCi)	Adult for 25 years (pCi)
U-238	6.72E-09	2.50E-09	4.16E-10	8.32E-10	1.34E-08	7.00E-09
Th-234	1.68E-09	6.24E-10	1.04E-10	2.08E-10	3.36E-09	1.75E-09
Pa-234m	2.44E-12	9.05E-13	1.51E-13	3.02E-13	4.87E-12	2.54E-12
U-234	6.72E-09	2.50E-09	4.16E-10	8.32E-10	1.34E-08	7.00E-09
Th-230	5.46E-09	2.03E-09	3.38E-10	6.76E-10	1.09E-08	5.69E-09
Ra-226	5.04E-08	1.87E-08	3.12E-09	6.24E-09	1.01E-07	5.25E-08
Rn-222	5.88E-10	2.18E-10	3.64E-11	7.28E-11	1.18E-09	6.13E-10
Po-218	1.18E-11	4.37E-12	7.28E-13	1.46E-12	2.35E-11	1.22E-11
Pb-214	7.14E-11	2.65E-11	4.42E-12	8.84E-12	1.43E-10	7.44E-11
Bi-214	5.46E-11	2.03E-11	3.38E-12	6.76E-12	1.09E-10	5.69E-11
Po-214	4.20E-18	1.56E-18	2.60E-19	5.20E-19	8.40E-18	4.37E-18
Pb-210	2.14E-07	7.96E-08	1.33E-08	2.65E-08	4.28E-07	2.23E-07
Bi-210	6.72E-10	2.50E-10	4.16E-11	8.32E-11	1.34E-09	7.00E-10
Po-210	6.30E-08	2.34E-08	3.90E-09	7.80E-09	1.26E-07	6.56E-08
Th-232	5.04E-09	1.87E-09	3.12E-10	6.24E-10	1.01E-08	5.25E-09
Ra-228	4.20E-08	1.56E-08	2.60E-09	5.20E-09	8.40E-08	4.38E-08
Ac-228	2.10E-10	7.80E-11	1.30E-11	2.60E-11	4.20E-10	2.19E-10
Th-228	4.62E-09	1.72E-09	2.86E-10	5.72E-10	9.24E-09	4.81E-09
Ra-224	1.60E-08	5.93E-09	9.88E-10	1.98E-09	3.19E-08	1.66E-08
Rn-220	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Po-216	1.26E-14	4.68E-15	7.80E-16	1.56E-15	2.52E-14	1.31E-14
Pb-212	2.31E-09	8.58E-10	1.43E-10	2.86E-10	4.62E-09	2.41E-09
Bi-212	1.30E-10	4.84E-11	8.06E-12	1.61E-11	2.60E-10	1.36E-10
Po-212	5.91E-21	2.20E-21	3.66E-22	7.32E-22	1.18E-20	6.16E-21
Tl-208	2.72E-12	1.01E-12	1.68E-13	3.37E-13	5.44E-12	2.83E-12
TOTAL U-238	3.50E-07	1.30E-07	2.16E-08	4.33E-08	6.99E-07	3.64E-07
TOTAL Th-232	7.03E-08	2.61E-08	4.35E-09	8.70E-09	1.41E-07	7.32E-08
TOTAL Ra-226	3.29E-07	1.22E-07	2.04E-08	4.07E-08	6.58E-07	3.43E-07
Th-232+0.1U-238	1.05E-07	3.91E-08	6.51E-09	1.30E-08	2.10E-07	1.10E-07

Table B-6. Exposure adjustment factors.

Location	Present Use Scenarios Food	Present Use Scenarios Outdoor Gamma	Future Use Scenarios Food	Future Use Scenarios Indoor Gamma	Inhalation of Soil
Base Conc.					
Th/Ra;1:0	1.0	1.0	1.0	1.0	1.0
Schools					
1	0.0	1.0	1.0	1.0	1.0
2	0.0	1.0	1.0	1.0	1.0
3-A	0.0	1.0	1.0	1.0	1.0
3-B	0.0	1.0	1.0	1.0	1.0
3-C\D	0.0	1.0	1.0	1.0	1.0
3 Base	0.0	1.0	1.0	1.0	1.0
Residences					
4-A	0.2	1.0	1.0	0.5	0.5
4-B	0.1	1.0	1.0	0.5	0.5
4 Base	0.2	1.0	1.0	0.5	0.5
5	1.0	0.5	0.8	0.5	0.8
6	0.1	1.0	1.0	0.5	0.8
7	1.0	1.0	1.0	1.0	1.0

Table B-7. West Chicago radiation risk estimates; present land use scenarios.

Location	Th-232 (pCi/g)*	Soil Ingestion Risk	Vegetable & Fruit Ingestion Risk	Inhalation of Particulates Risk	Inhalation of Th/Rn Risk	Internal Exposure Risk	External Gamma Exposure Risk	Present Use Total Risk
Base Conc.								
Th/Ra;1:0.1	1	3.2E-07	1.1E-06	1.1E-10	1.0E-05	1.1E-05	9.8E-06	2.1E-05
Schools - Children								
1	3	1.2E-07	-	9.7E-11	-	1.2E-07	1.8E-05	1.8E-05
2	3	2.0E-08	-	4.9E-11	-	2.0E-08	3.2E-06	3.3E-06
3-A	34	4.4E-07	-	1.1E-09	-	4.4E-07	2.4E-05	2.4E-05
3-B	34	4.4E-07	-	1.1E-09	-	4.4E-07	8.6E-06	9.1E-06
3-C\D	35	4.6E-07	-	1.1E-09	-	4.6E-07	2.2E-05	2.2E-05
3 Base	35	4.6E-07	-	1.1E-09	-	4.6E-07	2.4E-05	2.4E-05
Schools - Teachers								
1	3	3.3E-07	-	6.1E-10	-	3.3E-07	4.9E-05	4.9E-05
2	3	3.3E-07	-	6.1E-10	-	3.3E-07	1.8E-05	1.9E-05
3-A	34	3.7E-06	-	6.9E-09	-	3.7E-06	6.7E-05	7.1E-05
3-B	34	3.7E-06	-	6.9E-09	-	3.7E-06	2.4E-05	2.8E-05
3-C\D	35	3.8E-06	-	7.1E-09	-	3.8E-06	6.1E-05	6.5E-05
3 Base	35	3.8E-06	-	7.1E-09	-	3.8E-06	6.7E-05	7.1E-05
Residences								
4-A	780	2.5E-04	1.7E-04	4.3E-08	-	4.1E-04	1.9E-03	2.3E-03
4-B	780	2.5E-04	8.3E-05	4.3E-08	7.8E-04	1.1E-03	1.9E-03	3.0E-03
4 Base	780	2.5E-04	1.7E-04	4.3E-08	7.8E-04	1.2E-03	1.9E-03	3.1E-03
5	490	1.5E-04	5.2E-04	4.3E-08	-	6.7E-04	8.5E-05	7.6E-04
6	200	6.3E-05	2.1E-05	1.7E-08	-	8.4E-05	1.7E-04	2.5E-04
7	28	8.8E-06	3.0E-05	3.1E-09	-	3.9E-05	3.0E-04	3.4E-04

* All progeny of Th-232 and U-238 are assumed to be in secular equalibrium with the head of their respective chains. U-238 concentrations are 10 percent of those for Th-232.

Table B-8. West Chicago radiation risk estimates; future land use scenarios.

Location	Th-232 (pCi/g)*	Soil Ingestion Risk	Vegetable & Fruit Ingestion Risk	Inhalation of Particulates Risk	Inhalation of Th/Rn Risk	Internal Exposure Risk	External Gamma Exposure Risk	Future Use Total Risk
Base Conc.								
Th/Ra;1:0.1	1	3.2E-07	1.1E-06	1.1E-10	1.0E-05	1.1E-05	2.3E-04	2.4E-04
Schools								
1	3	9.5E-07	3.2E-06	3.3E-10	3.0E-05	3.4E-05	6.9E-04	7.2E-04
2	3	9.5E-07	3.2E-06	3.3E-10	3.0E-05	3.4E-05	6.7E-04	7.0E-04
3-A	34	1.1E-05	3.6E-05	3.7E-09	3.4E-04	3.9E-04	7.5E-03	7.9E-03
3-B	34	1.1E-05	3.6E-05	3.7E-09	3.4E-04	3.9E-04	7.7E-03	8.1E-03
3-C\D	35	1.1E-05	3.7E-05	3.8E-09	3.5E-04	4.0E-04	6.7E-03	7.1E-03
3 Base	35	1.1E-05	3.7E-05	3.8E-09	3.5E-04	4.0E-04	7.7E-03	8.1E-03
Residences								
4-A	780	2.5E-04	8.3E-04	4.3E-08	7.8E-03	8.9E-03	7.7E-02	8.6E-02
4-B	780	2.5E-04	8.3E-04	4.3E-08	7.8E-03	8.9E-03	7.7E-02	8.6E-02
4 Base	780	2.5E-04	8.3E-04	4.3E-08	7.8E-03	8.9E-03	7.7E-02	8.6E-02
5	490	1.5E-04	4.2E-04	4.3E-08	4.9E-03	5.5E-03	5.5E-02	6.0E-02
6	200	6.3E-05	2.1E-04	1.7E-08	2.0E-03	2.3E-03	1.9E-02	2.1E-02
7	28	8.8E-06	3.0E-05	3.1E-09	2.8E-04	3.2E-04	5.6E-03	5.9E-03

* All progeny of Th-232 and U-238 are assumed to be in secular equalibrium with the head of their respective chains. U-238 concentrations are 10 percent of those for Th-232.